



Re: United States Patent Application No. 10/659,229

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For : Magnetoresistance Effect Element, Magnetic Head, And
Magnetic Reproducing Apparatus

DECLARATION

I, Masahiko HYUGAJI, a national of Japan and a registered Japanese patent attorney of HYUGAJI & ASSOCIATES, Kannaifudosan, 4-168, Motomachi, Naka-ku, Yokohama-shi, Kanagawa 231-0861, Japan, do hereby declare:

THAT I was entrusted by, the applicants of the above-identified United States Patent Application, with the preparation of the Japanese language patent application of the previous patent application thereof (Japanese Patent Application No. 2002-265883) filed on September 11, 2002 and the above-identified United States Patent Application claiming the priority of said Japanese Patent Application;

THAT I am knowledgeable of and conversant in each of the Japanese and English languages;

I further declare that all statements made herein of my own knowledge are true and that all statements on information and belief are believed to be true.

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Date

Masahiko HYUGAJI



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【Title of the invention】

MAGNETORESISTANCE EFFECT ELEMENT, MAGNETIC HEAD, AND
MAGNETIC REPRODUCING APPARATUS

5 【SCOPE OF CLAIMS】

【Claim 1】

A magnetoresistance effect element comprising:

a magnetoresistance effect film including a first ferromagnetic
layer whose direction of magnetization is pinned substantially in one
10 direction, a second ferromagnetic layer whose direction of
magnetization changes in response to an external magnetic field,
and an intermediate layer provided between the first and second
ferromagnetic layers;

a pair of electrodes electrically coupled to the
15 magnetoresistance effect film and configured to supply a sense
current perpendicularly to a film plane of the magnetoresistance
effect film; and

a phase separation layer provided between the pair of
electrodes, the phase separation layer comprising a first phase and a
20 second phase formed by a phase separation in a solid phase from an
alloy including a plurality of elements, one of the first and second
phases including at least one element selected from the group
consisting of oxygen, nitrogen, fluorine and carbon in higher
concentration than other of the first and second phases.

25 【Claim 2】

The magnetoresistance effect element according to claim 1,
wherein

the alloy includes at least one element selected from the first
group consisting of silver, gold, platinum, palladium, iridium, osmium
5 and copper, and at least one element selected from the second group
consisting of nickel, iron and cobalt, and

in a case where the alloy is expressed by a formula
 $M_x(\text{Ni}_{100-y}(\text{Fe}_{100-z}\text{Co}_z)_y)_{100-x}$ where M denotes the element selected
from the first group, the composition x is in a range between 1
10 atomic % and 50 atomic %, the composition y is in a range between
0 atomic % and 50 atomic %, and the composition z is in a range
between 0 atomic % and 100 atomic %, or in a case where the alloy
is expressed by a formula $M_x(\text{Co}_{100-y}(\text{Fe}_{100-z}\text{Ni}_z)_y)_{100-x}$ where M
denotes the element selected from the first group, the composition x
15 is in a range between 1 atomic % and 50 atomic %, the composition
y is in a range between 0 atomic % and 50 atomic %, and the
composition z is in a range between 0 atomic % and 100 atomic %.

【Claim 3】

The magnetoresistance effect element according to claim 1,
20 wherein

the alloy includes aluminum, at least one element selected
from the first group consisting of silver, gold, platinum, palladium,
iridium, and osmium, and at least one element selected from the
second group consisting of magnesium, calcium, silicon, germanium,
25 boron, tantalum, tungsten, niobium, zirconium, titan, chromium,
zinc, lithium and gallium, and

in a case where the alloy is expressed by a formula
(Al_{100-y}Q_y)_{100-x}M_x where M denotes the element selected from the first
group and Q denotes the elements selected from the second group,
the composition x is in a range between 1 atomic % and 40 atomic %, 5
and the composition y is in a range between 0 atomic % and 30
atomic %.

【Claim 4】

The magnetoresistance effect element according to claim 1,
wherein

10 the alloy includes magnesium, at least one element selected
from the first group consisting of silver, gold, platinum, copper,
palladium and iridium, and at least one element selected from the
second group consisting of magnesium, calcium, silicon, germanium,
zirconium, lithium and gallium, and

15 in a case where the alloy is expressed by a formula
(Mg_{100-y}Q_y)_{100-x}M_x where M denotes the element selected from the
first group and Q denotes the elements selected from the second
group, the composition x is in a range between 1 atomic % and 40
atomic %, and the composition y is in a range between 0 atomic %
20 and 30 atomic %.

【Claim 5】

The magnetoresistance effect element according to claim 1,
wherein

the alloy includes silicon, at least one element selected from
25 the first group consisting of silver, gold, platinum, copper, palladium,
iridium and osmium, and at least one element selected from the

second group consisting of magnesium, calcium, magnesium, germanium, zinc, lithium and gallium, and

in a case where the alloy is expressed by a formula $(\text{Si}_{100-y}\text{Q}_y)_{100-x}\text{M}_x$ where M denotes the element selected from the first group and Q denotes the elements selected from the second group,
5 the composition x is in a range between 1 atomic % and 40 atomic %, and the composition y is in a range between 0 atomic % and 30 atomic %.

【Claim 6】

10 The magnetoresistance effect element according to claim 1, wherein

the alloy includes manganese, at least one element selected from the first group consisting of silver, gold, platinum, copper, palladium, iridium and osmium, and at least one element selected
15 from the second group consisting of magnesium, calcium, magnesium, germanium, zinc, lithium, gallium and silicon, and

in a case where the alloy is expressed by a formula $(\text{Mn}_{100-y}\text{Q}_y)_{100-x}\text{M}_x$ where M denotes the element selected from the first group and Q denotes the elements selected from the second
20 group, the composition x is in a range between 1 atomic % and 40 atomic %, and the composition y is in a range between 0 atomic % and 30 atomic %.

【Claim 7】

The magnetoresistance effect element according to one of
25 claims 1 through 6, wherein

the phase separation layer has a lamination of a first layer and

a second layer,

the first layer includes a plurality of phases formed by a phase separation in a solid phase from a first alloy, and

the second layer includes a plurality of phases formed by a phase separation in a solid phase from a second alloy different from the first alloy.

【Claim 8】

The magnetoresistance effect element according to one of claims 1 through 7, wherein

an average grain size of the other of the first and second phases is not smaller than 0.8 times thickness of the phase separation layer and is not larger than four times thickness of the phase separation layer, and

an average spacing of the other of the first and second phases is in a range between 1nm and 10 nm.

【Claim 9】

The magnetoresistance effect element according to one of claims 1 through 8, wherein

an average spacing of the other of the first and second phases is smaller than average crystal grain sizes of the first and second ferromagnetic layers.

【Claim 10】

A magnetoresistance effect element comprising:

a magnetoresistance effect film including a first ferromagnetic layer whose direction of magnetization is pinned substantially in one direction, a second ferromagnetic layer whose direction of

magnetization changes in response to an external magnetic field,
and an intermediate layer provided between the first and second
ferromagnetic layers;

a pair of electrodes electrically coupled to the
5 magnetoresistance effect film and configured to supply a sense
current perpendicularly to a film plane of the magnetoresistance
effect film;

a magnetic layer provided between the pair of electrodes, the
magnetic layer comprising a first region and a second region, the first
10 region including at least one element selected from the group
consisting of oxygen, nitrogen, fluorine and carbon in higher
concentration than the second region; and

a magnetic coupling interception layer provided between the
magnetic layer and the first or second ferromagnetic layer.

15 **【Claim 11】**

A magnetoresistance effect element comprising:

a magnetoresistance effect film including a first ferromagnetic
layer whose direction of magnetization is pinned substantially in one
direction, a second ferromagnetic layer whose direction of
20 magnetization changes in response to an external magnetic field,
and an intermediate layer provided between the first and second
ferromagnetic layers;

a pair of electrodes electrically coupled to the
magnetoresistance effect film and configured to supply a sense
25 current perpendicularly to a film plane of the magnetoresistance
effect film;

a magnetic layer provided between the pair of electrodes, the magnetic layer comprising a first region and a second region, the first region including at least one element selected from the group consisting of oxygen, nitrogen, fluorine and carbon in higher
5 concentration than the second region; and

a layer provided between the magnetic layer and the first or second ferromagnetic layer, the layer having a thickness between 1nm and 3nm and including at least one element selected from the group consisting of copper, gold, silver, rhenium, osmium, ruthenium,
10 iridium, palladium, chromium, magnesium, aluminum, rhodium and platinum.

【Claim 12】

A method of manufacturing a magnetoresistance effect element comprising a magnetoresistance effect film including a first
15 ferromagnetic layer whose direction of magnetization is pinned substantially in one direction, a second ferromagnetic layer whose direction of magnetization changes in response to an external magnetic field, and an intermediate layer provided between the first and second ferromagnetic layers, a pair of electrodes
20 electrically coupled to the magnetoresistance effect film and configured to supply a sense current perpendicularly to a film plane of the magnetoresistance effect film, comprising:

distributing a first and second phases in a film plane by inducing a phase separation in a layer made of an alloy including a
25 plurality of elements.

【Claim 13】

The method of manufacturing a magnetoresistance effect element according to claim 12, further comprising:

making at least one element selected from the group consisting of oxygen, nitrogen, fluorine and carbon react
5 preferentially with one of the first and second phases.

【Claim 14】

A magnetic head comprising the magnetoresistance effect element according to one of claims 1 through 11.

【Claim 15】

10 A magnetic reproducing apparatus comprising the magnetic head according to claim 14, and reading magnetic information in a magnetic recording medium.

【Detailed description of the invention】

【 0 0 0 1 】

15 **【Technical field to which the invention pertains】**

The present invention relates to a magnetoresistance effect element, a manufacturing method of a magnetoresistance effect element, a magnetic head and a magnetic reproduction apparatus, and more particularly, it relates to a magnetoresistance effect
20 element where a sense current flows perpendicularly to the film plane, a manufacturing method of the magnetoresistance effect element, and a magnetic head and a magnetic reproduction apparatus including the magnetoresistance effect element.

【 0 0 0 2 】

25 **【Prior art】**

Although a magnetic storage density of HDD (hard disk drive)

is improved dramatically in recent years, it has been desired to raise the magnetic storage density further. Since a record bit size becomes small as the magnetic storage density is raised, a reproducing sensitivity is lowered in the conventional thin film head. Therefore, now, the magnetoresistance effect type head (MR head) including a magnetoresistance effect (Magnetoresistive effect) has been used mainly. A spin valve (spin-valve) type giant magnetoresistance type head (SVGMR head) which shows a big magnetoresistance effect has attracted attention.

10 【 0 0 0 3 】

FIG. 22 is a schematic diagram which illustrates the outline section structure of the spin valve film. That is, the spin valve film 100 has the structure in which a ferromagnetic layer F, a non-magnetic layer S, a ferromagnetic layer P, and an antiferromagnetic layer A are laminated in this order.

The non-magnetic layer S is interposed between the two ferromagnetic layers F and P which are in a magnetically uncoupled state. Magnetization of one ferromagnetic layer P is fixed with an exchange bias using the antiferromagnetic material A, and whereas the magnetization of other ferromagnetic layer F is able to rotate easily by an external magnetic fields (signal magnetic field etc.). And a giant magnetoresistance effect can be obtained by rotating only magnetization of the ferromagnetic layer F by an external magnetic field and changing its magnetic orientation relative to that of the other magnetic layer (ex. reference to non-patent document 1).

25 【 0 0 0 4 】

【non-patent document 1】

Phys. Rev. B, Vol.45, 806 (1992), J. Appl. Phys. Vol.69, 4774 (1991)

【 0 0 0 5 】

Here, the ferromagnetic layer F is called a "free layer", a
5 "magnetic field reception layer", or a "magnetically free layer", the
ferromagnetic layer P is called a "pinned layer", a "magnetically
pinned layer" or a "magnetically fixed layer", and the non-magnetic
layer S is called a "spacer layer", "a magnetic coupling interception
layer", etc. in many cases.

10 【 0 0 0 6 】

In the case of the spin valve film, since magnetization of the
free layer F, i.e., a ferromagnetic layer, can be rotated also in the
lower field, it is possible to raise reproduction sensitivity and it is
suitable for MR element for MR heads.

15 【 0 0 0 7 】

In the case of such a spin valve element, it is necessary to
pass the "sense current" in order to detect a change of the resistance
caused by a magnetic field.

【 0 0 0 8 】

20 For this reason, the method of passing the sense current in
parallel to a film plane and measuring resistance of a parallel
direction to a film plane is generally used. Generally this method is
called the "CIP (current-in-plane)" system.

【 0 0 0 9 】

25 In the case of the CIP system, the value of about 10% through
20% can be obtained as a change rate of MR. Moreover, in the MR

head of the shield type used currently, the spin valve element is used in the plane shape almost near a square. Therefore, it is considered that the resistance of MR element is equal to the resistance of MR film plane. For this reason, in the spin valve film of a CIP system, a good
5 S/N characteristic can be obtained by making the resistance of the film plane into 5 ohms through 30 ohms. Resistance of this level can be easily made by making the thickness of the whole spin valve film thin. Therefore, generally the spin valve film of the CIP system is used as the MR element for MR heads currently.

10 【 0 0 1 0 】

On the other hand, the magnetoresistance effect element (hereafter called a "CPP type artificial lattice") where the sense current is passed perpendicularly (current perpendicular to plane: CPP) to the film plane in the artificial lattice in which a magnetic
15 material and a non-magnetic material are laminated is proposed as a method of obtaining big MR which exceeds 30%.

【 0 0 1 1 】

In a CPP type artificial lattice type magnetoresistance effect element, the electrode is provided in the upper and lower sides of the
20 artificial lattice in which the ferromagnetic layers and the non-magnetic layers are laminated by turns, and the sense current flows perpendicularly to the film plane. With this structure, since the probability that the sense current crosses a magnetic layer / non-magnetic layer interface becomes high, an interface effect can
25 be obtained and big change rate of MR can be obtained.

【 0 0 1 2 】

However, in using MR element for an MR head, it is necessary not only to control the magnetization of a magnetic layer and to enable it to measure an external magnetic field efficiently by it, but also to form each magnetic layer into a single magnetic domain so that a Barkhausen noise etc. may not occur simultaneously. However, as mentioned above, it is necessary to laminate magnetic layers and non-magnetic layers repeatedly by turns in order to earn resistance in the case of the CPP type MR element, therefore, it is technically very difficult to individually control the magnetization of each of such many the magnetic layers.

【 0 0 1 3 】

On the other hand, the CPP system can be adopted also in the spin valve structure using FeMn / NiFe / Cu / NiFe, FeMn / CoFe / Cu / CoFe, etc.

15 【 0 0 1 4 】

That is, the sense current is passed perpendicularly to the film plane of the laminated films which have a spin valve structure. However, since the number of pinned layers and free layers becomes much smaller than that of the artificial lattice type, the resistance falls further and a resistance rate of change also falls.

20 【 0 0 1 5 】

As for this point, the magnetoresistance effect element in which the non-magnetic film which consists of the mixture of an insulator and an electric conductor is inserted is proposed (ex. reference to patent document 1).

25 【 0 0 1 6 】

【patent document 1】

Japanese Patent No.3293437

【0017】

The CPP type magnetoresistance effect element in which the
5 non-magnetic film which has the structure where an insulator I
surrounds the electric conductors C is inserted is disclosed in FIG. 1
of Japanese Patent No.3293437. However, as the example of the
structure of the non-magnetic film disclosed in Japanese Patent
No.3293437, there is only an explanation that non-magnetic films
10 having thickness of 2nm or 5nm was deposited by using the
multi-component target including Al_2O_3 and Cu, and it is unknown
what kind of structure was made concretely as the non-magnetic
film.

【0018】

15 【Problems to be solved by the invention】

As explained above, various structures, such as a spin valve
film of a CIP type, an artificial lattice of a CPP type, and spin valve
film of a CPP type have been proposed. However, the present
magnetic storage density is continuing the rise of an annual rate of
20 60% or more, and the further output increase has been desired.
However, the spin valve film which can be used with high storage
density which exceeds 100 Gbits/inch² at present and which has
suitable resistance and the big amount of MR change, and serves as
high sensitivity magnetically is difficult to realize.

25 【0019】

The purpose of the invention is to provide the practical

magnetoresistance effect element, magnetic head, and magnetic reproducing apparatus which has suitable resistance while maintaining the spin dependent dispersion effect effectively.

【 0 0 2 0 】

5 **【Means for solving problem】**

 In order to achieve the purpose, according to the first embodiment of the invention, there is provided a magnetoresistance effect element comprising: a magnetoresistance effect film including a first ferromagnetic layer whose direction of magnetization is pinned substantially in one direction, a second ferromagnetic layer whose direction of magnetization changes in response to an external magnetic field, and an intermediate layer provided between the first and second ferromagnetic layers; a pair of electrodes electrically coupled to the magnetoresistance effect film and configured to supply a sense current perpendicularly to a film plane of the magnetoresistance effect film; and a phase separation layer provided between the pair of electrodes, the phase separation layer comprising a first phase and a second phase formed by a phase separation in a solid phase from an alloy including a plurality of elements, one of the first and second phases including at least one element selected from the group consisting of oxygen, nitrogen, fluorine and carbon in higher concentration than other of the first and second phases.

【 0 0 2 1 】

25 According to the above mentioned example, the practical magnetoresistance effect element which has suitable resistance can

be obtained while maintaining the spin dependent dispersion effect effectively.

【 0 0 2 2 】

According to the second embodiment of the invention, there is
5 provided a magnetoresistance effect element comprising: a
magnetoresistance effect film including a first ferromagnetic layer
whose direction of magnetization is pinned substantially in one
direction, a second ferromagnetic layer whose direction of
magnetization changes in response to an external magnetic field,
10 and an intermediate layer provided between the first and second
ferromagnetic layers; a pair of electrodes electrically coupled to the
magnetoresistance effect film and configured to supply a sense
current perpendicularly to a film plane of the magnetoresistance
effect film; a magnetic layer provided between the pair of electrodes,
15 the magnetic layer comprising a first region and a second region, the
first region including at least one element selected from the group
consisting of oxygen, nitrogen, fluorine and carbon in higher
concentration than the second region; and a magnetic coupling
interception layer provided between the magnetic layer and the first
20 or second ferromagnetic layer.

【 0 0 2 3 】

According to the above mentioned example, the practical
magnetoresistance effect element which has suitable resistance can
be obtained while maintaining the spin dependent dispersion effect
25 effectively.

【 0 0 2 4 】

According to the third embodiment of the invention, there is provided a magnetoresistance effect element comprising: a magnetoresistance effect film including a first ferromagnetic layer whose direction of magnetization is pinned substantially in one direction, a second ferromagnetic layer whose direction of magnetization changes in response to an external magnetic field, and an intermediate layer provided between the first and second ferromagnetic layers; a pair of electrodes electrically coupled to the magnetoresistance effect film and configured to supply a sense current perpendicularly to a film plane of the magnetoresistance effect film; a magnetic layer provided between the pair of electrodes, the magnetic layer comprising a first region and a second region, the first region including at least one element selected from the group consisting of oxygen, nitrogen, fluorine and carbon in higher concentration than the second region; and a layer provided between the magnetic layer and the first or second ferromagnetic layer, the layer having a thickness between 1nm and 3nm and including at least one element selected from the group consisting of copper, gold, silver, rhenium, osmium, ruthenium, iridium, palladium, chromium, magnesium, aluminum, rhodium and platinum.

【 0 0 2 5 】

According to the above mentioned example, the practical magnetoresistance effect element which has suitable resistance can be obtained while maintaining the spin dependent dispersion effect effectively.

【 0 0 2 6 】

A magnetoresistance effect element.

【 0 0 2 7 】

According to an embodiment of the invention, there is provided a method of manufacturing a magnetoresistance effect element comprising a magnetoresistance effect film including a first
5 ferromagnetic layer whose direction of magnetization is pinned substantially in one direction, a second ferromagnetic layer whose direction of magnetization changes in response to an external magnetic field, and an intermediate layer provided between the first and second ferromagnetic layers, a pair of electrodes
10 electrically coupled to the magnetoresistance effect film and configured to supply a sense current perpendicularly to a film plane of the magnetoresistance effect film, comprising: distributing a first and second phases in a film plane by inducing a phase separation in
15 a layer made of an alloy including a plurality of elements.

【 0 0 2 8 】

According to the above mentioned example, the practical magnetoresistance effect element which has suitable resistance can be easily manufactured while maintaining the spin dependent
20 dispersion effect certainly and effectively.

【 0 0 2 9 】

By mounting the first through third magnetoresistance effect element, the magnetic head of high sensitivity and the magnetic reproducing apparatus with high recording density can be obtained.

25 【 0 0 3 0 】

【Mode for carrying out the claimed invention】

Hereafter, some embodiment of the invention will be explained, referring to the drawings.

【 0 0 3 1 】

(First embodiment)

5 FIG. 1 is a schematic diagram showing the cross-sectional structure of the magnetoresistance effect element according to the first embodiment of the present invention.

In this figure, reference numeral 1 corresponds to a substrate electrode, 2 corresponds to a base layer, 3 corresponds to an
10 antiferromagnetic layer, 4 corresponds to a magnetically fixed layer (pinned layer), 5A corresponds to a magnetic coupling interception layer, 5B corresponds to an interface adjustment layer, 6 corresponds to a magnetically free layer (free layer), 7 corresponds to a protective layer, 8 corresponds to an upper electrode layer, and 9
15 corresponds to a phase separation layer.

That is, this element is a CPP type magnetoresistance effect element where the sense current I flows (in a direction of the arrow of this figure or opposite direction thereto) between the substrate electrode 1 and the upper electrode layer 9.

20 【 0 0 3 2 】

And magnetic coupling interception layer 5A, interface adjustment layer 5B, and the phase separation layer 9 have a role as an intermediate layer (spacer layer) which intercepts the magnetic coupling between the magnetically fixed layer 4 and the magnetically
25 free layer 6.

【 0 0 3 3 】

Moreover, the phase separation layer 9 has the role of making the substantial element size smaller effectually and enlarging the amount of resistance change, by narrowing down the current path of the sense current I.

5 【 0 0 3 4 】

FIG. 2 is a diagram which illustrates that the phase separation layer 9 narrows down the sense current. As illustrated in FIG. 2, since two-dimensional "variation" of the resistance is provided in the film plane of the phase separation layer 9 and there are portions to which the current concentrates, such a current constriction effect is produced.

Namely, the resistance of the phase separation layer 9 varies two dimensionally, and the phase separation layer 9 has a region 9A where the resistance is relatively higher and regions 9B where the resistance is relatively lower. The sense current I supplied to the spin valve film from the electrode is blocked by the region 9A of higher resistance, and flows through the regions 9B of lower resistance formed locally in the phase separation layer 9. In this embodiment, since the current flows through such regions 9B of lower resistance, the current characteristic about the phase separation layer 9 maintains the "ohmic nature".

20 【 0 0 3 5 】

On the other hand, in the case of the so-called TMR (tunneling magnetoresistance effect) element, an insulating layer is provided between a pair of magnetic material layers, and the sense current passes through this insulating layer by tunneling. Therefore, the

current characteristic over the insulating layer in a TMR element shows a so-called "tunneling characteristic."

【 0 0 3 6 】

In contrast, in the magnetoresistance effect element of this embodiment, it is the point that sense current passes the regions 9B of lower resistance of the phase separation layer 9, and the ohmic nature is essentially obtained. Therefore, the temperature characteristics of the current differ greatly from that of the TMR element, for example.

10 【 0 0 3 7 】

One of the methods of investigating whether the current flowing nature depends on the ohmic current path or on the tunneling mechanism of TMR is to investigate a relation between the sense current and a magnetoresistance effect. That is, in the case of TMR, when the resistance of the element is low, since a breakdown takes place easily, stability cannot be acquired. When a tendency of a change rate of magnetoresistance to decrease with an increase of the sense current is seen, a possibility of being TMR is very high.

【 0 0 3 8 】

20 Alternatively, they can be distinguished by investigating the temperature dependency of resistance. That is, in the case of an ohmic system, the resistance decreases if the temperature is lowered down to about minus 200 degrees centigrade from the room temperature, while the resistance increases in the case of TMR.

25 【 0 0 3 9 】

FIG. 3 is a schematic diagram showing the example of the

planar structure of the phase separation layer 9. As shown in this figure, in the phase separation layer 9, the region 9A of higher resistance and the regions 9B of lower resistance exist separately.

【 0 0 4 0 】

5 The two-dimensional separation structure is formed by a phase separation in a solid phase, such as "spinodal decomposition" and "GP zone (Guinier-Preston zone)." That is, the phase separation layer 9 provided between the magnetically pinned layer 4 and the magnetically free layer 6 has a structure where a phase separation in
10 a solid phase into two or more phases by mechanisms such as spinodal decomposition and formation of GP zone has taken place in an alloy which consists of two or more kinds of elements.

【 0 0 4 1 】

 Moreover, in this embodiment, either one of two or more
15 phases separated by such a phase separation mechanism is oxidized preferentially by a treatment such as an exposure to an oxygen atmosphere, oxygen radical irradiation and heat treatment. That is, the region 9A (insulating phase) of higher resistance is formed by carrying out oxidization process of a part of phase separation layer
20 phase-separated in a solid phase with mechanisms, such as spinodal decomposition and formation of GP zone. And the regions 9B (electric conduction phase) of a lower resistance with non-oxidized state are distributed in the region 9A.

 Nitridation, fluoridation or carbonization may also be used
25 instead of oxidation, as will be detailed later.

 Some alloy systems have a phase separation which produce a

high electric conduction phase 9B and a insulating phase 9B having a resistance 10 times or more than 100 times larger than the resistance of the conduction phase 9B, thus oxidation process is not needed.

5 【 0 0 4 2 】

According to the embodiment, it becomes easy to form the phase separated structure having the regions 9A and 9B by using the phase separation in a solid phase such as spinodal decomposition, formation of GP zone, etc. It also becomes certain and easy to control the ratio and distribution of the separated phases.

10 【 0 0 4 3 】

According to examination of the inventors, it has turned out that the practical CPP type magnetoresistance effect element which has suitable resistance can be obtained while maintaining the spin dependent dispersion effect effectively, when the particle diameter of high electric conduction phase 9B is 0.8 to 4 times larger than the thickness of the phase separation layer 9 and when the average interval of the neighboring high electric conduction phases is made in a range from 1nm to 10nm. The particle diameter and an interval of high electric conduction phases can be measured by TEM (transmission electron microscopy).

20 【 0 0 4 4 】

By using spinodal decomposition or the phase separation mechanism of GP zone formation, the particle diameter and interval of the high electric conduction phase are regularly controllable by adjusting the material composition of the phase separation layer 9,

and/or by adjusting the conditions of the phase separation promotion process (for example, heat treatment, ion irradiation of rare gas such as Ar, plasma irradiation of rare gas such as Ar, etc.).

Moreover, the result is sufficiently reproducible. Therefore, the ratio
5 of the high electron conduction phase in the phase separation layer 9 can be precisely controlled into the range mentioned above, and thus, magnetoresistance effect elements which have a desired characteristic can be produced reproducibly.

【 0 0 4 5 】

10 On the other hand, in the case of using a phase separation layer consisting of an Al_2O_3 insulating part and a Cu conductive part examined as a comparative example, since the interval of the conductive parts is determined by the particle diameter of the magnetically fixed layer or the magnetically free layer which lies
15 under the phase separation layer, the interval of the conductive parts tends to be 10nm or more, and they become sparse. In such a case, if a storage density rises and element size becomes smaller, the number of the conductive parts in an element will become fewer. Therefore, it will become difficult to control the ratio that the high
20 electric conduction phases occupy in the phase separation layer, and thus, it will become difficult to control the element resistance and the amount of resistance change.

【 0 0 4 6 】

FIG. 4 is a flow chart showing a part of formation process of
25 the phase separation layer 9 in the embodiment of the invention.

【 0 0 4 7 】

FIGs. 5A through 5C are schematic diagrams which illustrate change of the planar structure of the phase separation layer 9.

【 0 0 4 8 】

When forming the phase separation layer 9, the base material
5 M is formed first in step S1. The base material M can be deposited in a form of a thin film by methods, such as a sputtering.

【 0 0 4 9 】

FIG. 5A shows the state where spinodal decomposition or formation of GP zone is not yet seen in the base material M. That is,
10 the base material M is almost uniform during or immediately after the deposition process.

【 0 0 5 0 】

In the embodiment, the phase decomposition process S2 may be carried out simultaneously or after the deposition process of the
15 base material M. As the decomposition process, a prolonged annealing at high temperature, irradiation of an ion beam, etc. can be mentioned.

【 0 0 5 1 】

By carrying out such a decomposition process in step S2, a
20 spatial modulation in concentration takes place in the base material M and the material M will decompose into a phase D1 and a phase D2, as shown in FIG. 5B. Generally, in the case of spinodal decomposition, a nucleation does not take place but a fluctuation of composition becomes larger continuously. Therefore, it is considered that there is
25 no incubation period, and decomposition takes place while keeping the conformity with a matrix perfectly.

In the case of the aluminum (Al) -4% copper (Cu) alloy, by an aging treatment at a room temperature or at an elevated temperature, a phase separation will takes place by forming a precipitated phase including copper with higher composition. For example, if the so-called "two-step ageing process" which includes an aging treatment at room temperature and a following precipitating process at elevated temperature is performed, a phase separated structure where minute regions having a higher concentration of copper is distributed uniformly in a matrix will be acquired.

【 0 0 5 2 】

As explained above, "variation" of composition takes places in the base material M by the decomposition process. As a result, the phase separation structure which is illustrated in FIG. 5B is formed.

【 0 0 5 3 】

Next, an oxidization process is carried out as step S3. As the oxidization process S3, a method of exposing to an atmosphere includes oxygen in the film forming chamber or a method of irradiating an oxygen radical, etc. can be used. Instead of the oxidization, a nitridation, fluoridation, or carbonization can be appropriately used according to the base material M.

【 0 0 5 4 】

By such an oxidization process, one of the separated phases D1 and D2 having a composition easy to be oxidized is oxidized preferentially. In the example shown in FIG. 5C, the phase D1 is oxidized and the region 9A of higher resistance is formed. On the

other hand, the phase D2 which is hardly oxidized constitutes the region 9B of lower resistance.

【 0 0 5 5 】

FIG. 6 is a flow chart showing another method of forming the
5 phase separation layer 9.

【 0 0 5 6 】

That is, it is not necessary to carry out the phase decomposition process and the oxidization process separately, and they may be carried out simultaneously.

10 【 0 0 5 7 】

For example, it is possible to expose the layer 9 to an oxygen atmosphere or to irradiate an oxygen radical simultaneously with the annealing treatment for phase separation. Thus, steps S2 and S3 can be carried out simultaneously.

15 【 0 0 5 8 】

Furthermore, the process of decomposition and oxidization can also be carried out simultaneously with the deposition process of the base material M. For example, it is also possible to carry out the deposition process, the phase decomposition process and the
20 oxidization process simultaneously, by irradiating the substrate with an ion beam which contains oxygen ion during the film forming process of the base material M.

【 0 0 5 9 】

As explained above, when the decomposition process S2 and
25 the oxidization process S3 are carried out simultaneously, the base material M is oxidized and a part of the region 9A of high resistance

may be constituted.

【 0 0 6 0 】

FIG. 7 is a conceptual sectional view showing the example of the phase separation in two or more kinds of separated solid phases.

5 In the case of this example, since the base material of the phase separation layer 9 consists of an element which carries out two or more phase separations of solid phases, two kinds of spinodal decompositions are carried out in the phase separation layer 9.

Consequently, in the phase separation layer 9, the regions 9A
10 (D1) and 9A (D2) of high resistance formed by the phase D1 and phase D2 being oxidized, and an electric conduction phase 9B of the low resistance formed of metallic elements which are different from the regions 9A (D1) and 9A (D2) of high resistance are formed.

A structure of three or more phases which includes two or
15 more kinds of phases of higher resistance and a phase of lower resistance can also be used as the phase separation layer 9 of the embodiment.

【 0 0 6 1 】

On the other hand, the method of irradiating an ion beam as
20 illustrated in FIG. 8 is also effective as the decomposition process S2 which accelerates a phase separation such as spinodal decomposition and GP zone formation in the embodiment. That is, by irradiating an ion beam, the energy for producing variation of composition in the base material M formed in a shape of a thin film is
25 given, and the phase separation is accelerated.

【 0 0 6 2 】

Rare gas elements, such as argon (Ar), xenon (Xe), and krypton (Kr), can be used as the ion beam in this case. When carrying out simultaneously with an oxidization (or nitridation, fluoridation, carbonization) process, oxygen (or nitrogen, fluoride, carbon) can also be used as the source of the ion beam.

【 0 0 6 3 】

The irradiation condition can be appropriately chosen so that etching of the base material M of the phase separation layer 9 does not take place notably. For example, an argon ion beam can be irradiated with about 50 volts of accelerating voltage and about 50 watts of electric power.

【 0 0 6 4 】

Next, the example of the base material M of the phase separation layer of this embodiment will be explained.

15 【 0 0 6 5 】

As one of the base materials M of the separation layer 9 which has the phase separation structure in a solid phase, an alloy of a noble metal element and one of nickel (Ni), iron (Fe) and cobalt (Co) can be used.

20 As the noble metal, silver (Ag), gold (Au), copper (Cu), platinum (Pt), palladium (Pd), iridium (Ir), osmium (Os) or copper (Cu) can be used.

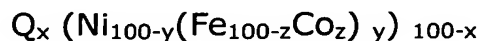
【 0 0 6 6 】

If an oxidization process is performed by using the oxygen radical previously stated to the alloy of noble metal-Ni-Fe or alloy of noble metal-Ni-Co, the phase (D1) which has higher composition of

Ni-Fe or Ni-Co is oxidized selectively and a high insulating phase (region 9A) is formed. By performing a heat treatment after forming the laminated structure of the magnetoresistance effect film, the phase separation of the phase separation layer 9 into the electric
5 conduction phase (noble metal) and an insulating phase (Ni-Fe-O_x and Ni-Co-O_x) is accelerated. Thus, the purity of the noble metal in the electric conduction phase increases, and the resistance thereof becomes lower.

【 0 0 6 7 】

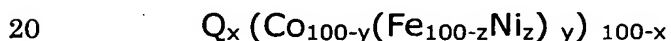
10 Such a phase separation and a selective oxidization can be realized with alloys expressed by the following formula:



where Q is the noble metal element. In the above formula, it is desirable that the following conditions are satisfied:

- 15 $1 \leq x \text{ (atomic \%)} \leq 50;$
 $0 \leq y \text{ (atomic \%)} \leq 50;$ and
 $0 \leq z \text{ (atomic \%)} \leq 100.$

Alloys expressed by the following formula can also be used as the material of the phase separation layer 9:



where Q is the noble metal element. In the above formula, it is desirable that the following conditions are satisfied:

- $1 \leq x \text{ (atomic \%)} \leq 50;$
 $0 \leq y \text{ (atomic \%)} \leq 50;$ and
25 $0 \leq z \text{ (atomic \%)} \leq 100.$

【 0 0 6 8 】

Here, it is desirable to use at least one of silver (Ag), gold (Au), platinum (Pt), palladium (Pd), iridium (Ir), osmium (Os), and the copper (Cu) as the "noble metal element". Moreover, instead of using only one noble metal element, two or more kinds of noble metal elements may also be incorporated in an alloy.

【 0 0 6 9 】

In this case, the composition x of the noble metal Q is a total sum of the compositions of the selected noble metal elements. For example, when silver and platinum are chosen as the noble metal elements Q, the composition x is the total sum of silver composition and platinum composition.

【 0 0 7 0 】

Alternatively, alloys expressed by the following formula may also be used as the material of the phase separation layer 9:

15 $(Al_{100-y}Q_y)_{100-x}M_x$

where element M is at least one of silver (Ag), gold (Au), platinum (Pt), copper (Cu), palladium (Pd), iridium (Ir) and osmium (Os), and element Q is at least one of magnesium (Mg), calcium (Ca), silicon (Si), germanium (Ge), boron (B), tantalum (Ta), tungsten (W), niobium (Nb), a zirconium (Zr), titanium (Ti), chromium (Cr), zinc (Zn), lithium (Li), and gallium (Ga).

Further, it is desirable that the following conditions are satisfied:

$$1 \leq x \text{ (atomic \%)} \leq 40.$$

25 $0 \leq y \text{ (atomic \%)} \leq 50$

【 0 0 7 1 】

In this alloy system, a phase separation into a phase with higher aluminum composition and a phase with lower aluminum composition takes place. Therefore, the phase (region 9A) of higher resistance in which aluminum and element Q is oxidized, and the metal (M) phase (region 9B) of lower resistance with comparatively higher purity can be obtained by performing oxidization process.

Furthermore, spinodal decomposition or nucleation are accelerated at lower temperature by making the composition x in a range between 1 % and 40 % and using the thin film formation techniques, such as the sputtering method.

It is more desirable to make the composition x in a range between 5 % and 20 %.

【 0 0 7 2 】

FIG. 9A is a schematic diagram of the TEM image of the section of the phase separation layer which is phase-separated from the base material of $\text{Al}_{90}\text{Ag}_{10}$ and experienced an oxidization process. FIG. 9B is a schematic diagram showing the profile of the element analysis by nano-EDX (Energy Dispersive X-ray photoelectron spectroscopy) of this phase separation layer.

【 0 0 7 3 】

The regions where composition of aluminum (Al) is higher are oxidized and the phase D1 of higher resistance is formed, and the regions where silver (Ag) composition is high form the phase D2 of lower resistance.

【 0 0 7 4 】

On the other hand, alloy system expressed by the following

formula may also be used as the base material of the phase separation layer 9: $(\text{Mg}_{100-y}\text{Q}_y)_{100-x}\text{M}_x$ where the element M is at least one of silver (Ag), gold (Au), platinum (Pt), palladium (Pd), copper (Cu), iridium (Ir), and osmium (Os), and the element Q is at least one of calcium (Ca), silicon (Si), germanium (Ge), zinc (Zn), lithium (Li), and gallium (Ga). Further, it is desirable that the following conditions are satisfied: $1 \leq x$ (atomic %) ≤ 40 ; and $0 \leq y$ (atomic %) ≤ 30 .

【 0 0 7 5 】

10 In this alloy system, a phase separation into a phase with higher magnesium composition and a phase with lower magnesium composition takes places. Therefore, the phase (region 9A) of high resistance in which magnesium and element Q is oxidized, and the metal (M) phase (region 9B) of low resistance with comparatively high purity can be obtained by performing oxidization process. Furthermore, spinodal decomposition or nucleation are accelerated at lower temperature by making the composition x in a range between 1 % and 40 % and by using the thin film formation techniques, such as the sputtering method. It is more desirable to make the composition x into a range between 5 % and 20 %.

【 0 0 7 6 】

Alternatively, alloys expressed by the following formula may also be used as the material of the phase separation layer 9: $(\text{Si}_{100-y}\text{Q}_y)_{100-x}\text{M}_x$ where element M is at least one of silver (Ag), gold (Au), platinum (Pt), copper (Cu), palladium (Pd), iridium (Ir) and osmium (Os), and element Q is at least one of magnesium (Mg),

calcium (Ca), germanium (Ge), zinc (Zn), lithium (Li), and gallium (Ga). Further, it is desirable that the following conditions are satisfied: $1 \leq x$ (atomic %) ≤ 40 ; and $0 \leq y$ (atomic %) ≤ 30 .

【 0 0 7 7 】

5 In this alloy system, a phase separation into a phase with higher silicon composition and a phase with lower silicon composition takes place. Therefore, the phase (region 9A) of higher resistance in which silicon and element Q is oxidized, and the metal (M) phase (region 9B) of lower resistance with comparatively higher purity can
10 be obtained by performing oxidization process.

Furthermore, spinodal decomposition or nucleation are accelerated at lower temperature by making the composition x in a range between 1 % and 40 % and using the thin film formation techniques, such as the sputtering method.

15 It is more desirable to make the composition x in a range between 5 % and 20 %.

【 0 0 7 8 】

Alternatively, alloys expressed by the following formula may also be used as the material of the phase separation layer 9:
20 $(\text{Mn}_{100-y}\text{Q}_y)_{100-x}\text{M}_x$ where element M is at least one of silver (Ag), gold (Au), platinum (Pt), copper (Cu), palladium (Pd), iridium (Ir) and osmium (Os), and element Q is at least one of magnesium (Mg), calcium (Ca), germanium (Ge), zinc (Zn), lithium (Li), and gallium (Ga). Further, it is desirable that the following conditions are
25 satisfied: $1 \leq x$ (atomic %) ≤ 40 ; and $0 \leq y$ (atomic %) ≤ 30 .

【 0 0 7 9 】

In this alloy system, a phase separation into a phase with higher manganese composition and a phase with lower manganese composition takes place. Therefore, the phase (region 9A) of higher resistance in which manganese and element Q is oxidized, and the metal (M) phase (region 9B) of lower resistance with comparatively higher purity can be obtained by performing oxidization process.

Furthermore, spinodal decomposition or nucleation are accelerated at lower temperature by making the composition x in a range between 1 % and 40 % and using the thin film formation techniques, such as the sputtering method. It is more desirable to make the composition x in a range between 5 % and 20 %.

【 0 0 8 0 】

On the other hand, in order to form GP zone, aluminum (Al)-copper (Cu) alloy, aluminum (Al)-silver (Ag) alloy, aluminum (Al)-zinc (Zn)-magnesium (Mg) alloy, etc. can be used.

【 0 0 8 1 】

In the base material alloy of the phase separation layer 9 explained above, in order to control the amount of oxygen absorption and to control the particle diameter of spinodal decomposition or a precipitated phase, an addition of the elements, such as chromium (Cr), titanium (Ti), zirconium (Zr), hafnium (Hf), molybdenum (Mo), tin (Sn), lithium (Li), and zinc (Zn) by few atomic % may be carried out.

【 0 0 8 2 】

Moreover, the material which contains two or more sorts of the base materials can be used.

Alternatively, a base material which induce a solid-phase separation such as spinodal decomposition, and an alloy which does not produce a separation in a solid phase can be laminated.

Thus, an insulating phase and an electric conduction phase
5 can be uniformly formed in a predetermined ratio by the phase separation in a solid phase, such as spinodal decomposition.

Moreover, it becomes possible to achieve an improvement in the breakdown voltage of the phase separation layer 9 by laminating an insulating phase which consists of metallic elements different
10 from the above-mentioned insulated phase.

【 0 0 8 3 】

Moreover, generation of pinholes decreases sharply by laminating two or more sorts of different base materials. A base material accompanied by the phase separation such as spinodal
15 decomposition, and an alloy without phase separation can be laminated.

【 0 0 8 4 】

FIG. 10 is a schematic diagram which illustrates the cross-sectional structure of the phase separation layer 9 which has a laminated structure. That is, the phase separation layer 9 of this
20 example has the structure which laminated a first phase separation layer 9' and a second phase separation layer 9." The first phase separation layer 9' has the region 9A' of higher resistance, and the regions 9B' of lower resistance. The second phase separation layer 9" has the region 9A" of higher resistance, and the regions 9B" of lower
25 resistance.

【 0 0 8 5 】

The average size of the regions 9B' is larger than that of regions 9B", and these regions are formed so that it may overlap mostly. Such structure can be formed by appropriately changing the composition of the base material of the first phase separation layer 9' and the second phase separation layer 9", or by changing the kind of the base material. That is, the sizes of the separated phases formed by the phase separation are controllable by changing the composition of the base materials or kind of the base materials of the upper and lower layers.

【 0 0 8 6 】

For example, on a phase separation layer 9" which consists of a material excellent in spinodal decomposition nature which was mentioned above, a phase separation layer 9' which includes an oxide (or nitride, boride, carbide) of elements which is easy to form crystalline state, such as chromium (Cr), tantalum (Ta), niobium (Nb), boron (B), germanium (Ge), tungsten (W), molybdenum (Mo), zirconium (Zr), titanium (Ti), vanadium (V), cobalt (Co), iron (Fe), nickel (Ni), and silicon (Si), can be laminated

By employing such a laminated structure, it becomes possible to improve the crystallinity of the magnetic layer formed on the phase separation layer in addition to be able to form the high electric conduction phase by spinodal decomposition, and improvement in the soft magnetic characteristic can be obtained.

【 0 0 8 7 】

Or a phase separation layer which consists of a material

excellent in the spinodal decomposition nature containing a magnetic oxide (or nitride, boride, carbide), such as cobalt (Co), iron (Fe), and nickel (Ni), and a phase separation layer which consists of an oxide (or nitride, boride, carbide) of non-magnetic element can be
5 laminated. The latter non-magnetic phase separation layer acts as a magnetic coupling interception layer, and thus, a reproducible current constriction effect and a magnetic coupling interception effect can be obtained simultaneously.

【 0 0 8 8 】

10 Moreover, if the spinodal decomposition takes place in either the upper layer or the lower layer when a separation process is carried out for such a lamination structure, the separated phases (D1, D2) may serve as a "trigger" for the spinodal decomposition in the other layer.

15 【 0 0 8 9 】

Consequently, it becomes possible to form the regions 9A' and 9A'' formed in the upper and lower layers 9' and 9'' so that they are overlapped in a thickness direction.

【 0 0 9 0 】

20 Although the phase separation layer of two-layered structure is illustrated in FIG. 10, the present invention is not limited to this example but may have a structure which has three or more phase separation layers laminated each other. Furthermore, the boundary of each layer may not necessarily be clear and may have a structure
25 where composition is modulating continuously along the direction of thickness of the phase separation layers.

【 0 0 9 1 】

Furthermore, the phase separation layer 9 may be inserted in the magnetically pinned layer 4, the magnetically free layers 6, the substrate electrode 1 and/or the upper electrode 8 in order to
5 improve the magnetic characteristic, to adjust the resistance, or to improve the crystallinity.

For example, a structure like magnetically pinned layer 4 / phase separation layer 9 / magnetically pinned layer 4', and magnetically pinned layer 4 / phase separation layer 9 / magnetically
10 pinned layer 4' can be mentioned.

【 0 0 9 2 】

On the other hand, in order to form the region 9A of relatively high resistance by raising resistance of the separated phase, the process of nitridation, fluoridation or carbonization can also be used
15 instead of oxidization in the phase separation layer 9. That is, when the electric resistance of the separated phase can be raised by making it react with nitrogen (N), fluoride (F), or carbon (C), the process of nitridation, fluoridation or carbonization can be used.

【 0 0 9 3 】

20 (Second embodiment)

Next, as a second embodiment of the invention, the magnetoresistance effect element where the phase separation layer 9 is provided either in a magnetically pinned layer, a magnetically free layer or an intermediate layer, or between the electrode and a
25 ferromagnetic film, and which contains a magnetic coupling interception layer which is adjoining the above-mentioned phase

separation layer, will be explained.

【 0 0 9 4 】

In the magnetoresistance effect element of this embodiment,
the magnetic coupling interception layer 5A can be provided at least
5 one side of the phase separation layer 9 as illustrated in FIG. 1.

The magnetic coupling interception layer 5A has the role which
intercepts certainly the magnetic coupling between the magnetically
pinned layer 4 and the magnetically free layer 6.

That is, even if the magnetic coupling between the
10 magnetically pinned layer 4 and the magnetically free layer 6 cannot
fully be intercepted only with the phase separation layer 9, the
magnetic coupling can be certainly intercepted by providing the
magnetic coupling interception layer 5A.

【 0 0 9 5 】

15 Such magnetic coupling interception layer 5A is especially
effective when an alloy system expressed by the formula
 $Q_x(\text{Ni}_{100-y}(\text{Fe}_{100-z}\text{Co}_z)_y)_{100-x}$ where Q denotes a noble metal element
is used as the base material of the phase separation layer 9. That is,
when a phase separation takes place in this alloy system to form the
20 region 9A, magnetism may remain a little in the region 9A oxidized
inadequately. In such a case, in order to intercept the magnetic
coupling between the neighboring magnetically free layers 6 and the
magnetically pinned layers 4, the magnetic coupling interception
layer 5A is especially effective.

25 【 0 0 9 6 】

As a material of the magnetic coupling interception layer 5A,

one of copper (Cu), gold (Au), silver (Ag), a rhenium (Re), osmium (Os), ruthenium (Ru), iridium (Ir), palladium (Pd), chromium (Cr), magnesium (Mg), aluminum (Al), rhodium (Rh) and platinum (Pt) can be used.

5 【 0 0 9 7 】

As for the thickness of the magnetic coupling interception layer 5A, it is desirable that it is thick enough to fully intercept the magnetic coupling between the magnetically pinned layers 4 and the magnetically free layers 6 through the phase separation layer 9. That is, since the magnetism may remain in the phase separation layer 9 as mentioned above, it is required for either of the magnetic coupling interception layers 5 provided in the upper and lower sides to have the thickness which can intercept the magnetic coupling certainly.

【 0 0 9 8 】

15 From this viewpoint, since this magnetic coupling will not be intercepted and the magnetization direction of the magnetically free layer 6 or the magnetically pinned layer 4 may be disturbed if the thickness of the magnetic coupling interception layer 5A is less than 0.5nm, it is desirable to set the thickness of the magnetic coupling interception layer 5A to 0.5 nm or more.

20 【 0 0 9 9 】

However, if the thickness of the magnetic coupling interception layer 5A becomes thick, the current narrowed in the phase separation layer 9 will spread again in the magnetic coupling interception layer 5A, and the current narrowed effect will decrease. From this viewpoint, as for the thickness of the magnetic coupling

interception layer 5A, it is desirable that it is 5nm or less.

【 0 1 0 0 】

In order to intercept the magnetic coupling and to control the spread of the current, it is more desirable to set the thickness of the magnetic coupling interception layer 5A in a range between 1nm and 3nm. The magnetic coupling interception layer may be provided in the upper and lower sides of the phase separation layer.

【 0 1 0 1 】

Alternatively, the magnetic coupling interception layer 5A may be provided in the upper side of the phase separation layer, and the interface adjustment layer 5B may be provided in the lower side of the phase separation layer. The interface adjustment layer 5B has a role of a buffer layer which controls grain size and crystallinity of the phase separation layer 9 and the magnetically free layer 6 formed thereon.

In order for prevent the spreading of the sense current, it is desirable to make the thickness of the interface adjustment layer 5B thin. For this reasons, as for the thickness of the interface adjustment layer 5B, it is desirable that it is less than 1 nm, and it is more desirable that it is 0.25 nm or less.

【 0 1 0 2 】

The interface adjustment layer 5B does not necessarily need to be a continuous film, and may be partially missing along the film plane. That is, the interface adjustment layer 5B can be a discontinuous thin film, as long as it has the buffering effect over the magnetically free layer 6.

【 0 1 0 3 】

On the other hand, as another laminated structure, the feature as above mentioned above can also be provided in the magnetoresistance effect element having the so-called "dual spin
5 valve structure" where the magnetically pinned layers are provided in the upper and lower sides of the magnetically free layer, respectively.

【 0 1 0 4 】

The metal magnetic material which includes nickel (Ni), iron
10 (Fe) or cobalt (Co) as a main component can be used as a material of the magnetically free layer 6 of the magnetoresistance effect element of this embodiment. It is required that the material of the free layer 6 should have the good soft magnetic characteristic to increase the sensitivity of a magnetic sensor and to decrease a
15 Barkhausen noise.

Also, it is desirable to grow the magnetically free layer 6 in the direction of a crystal axis [111] which is the stacking direction of a closest-packed atomic plane of a face-centered cubic lattice.

【 0 1 0 5 】

20 On the other hand, the magnetically free layer 6 may have a body-centered cubic lattice partially, or may have the crystal structure of a hexagonal close-packed lattice or others.

Moreover, the so-called "synthetic antiferromagnetic structure" where the magnetic material of two or more layers are
25 combined in an antiferromagnetic fashion through nonmagnetic materials, such as a ruthenium (Ru), may be incorporated in the

magnetically pinned layer 4 of the magnetoresistance effect element of this embodiment.

【 0 1 0 6 】

(Third embodiment)

5 Next, the magnetoresistance effect element where the phase separation layer is provided between the magnetically free layer and the electrode will be explained as the third embodiment of the invention.

【 0 1 0 7 】

10 FIG. 11 is a schematic diagram which illustrates the cross-sectional structure of the magnetoresistance effect element according to this embodiment. The same reference numerals are given to the same elements as what were mentioned above with reference to FIG. 1 through FIG. 11 about this figure, and detailed
15 explanation will be omitted.

【 0 1 0 8 】

In this example, the non-magnetic metal layer 10 is provided between the magnetically pinned layer 4 and the magnetically free layer 6. This non-magnetic metal layer has a role to intercept the
20 magnetic coupling between the magnetically pinned layer 4 and the magnetically free layer 6.

【 0 1 0 9 】

And the phase separation layer 9 is provided between the magnetically free layer 6 and the upper electrode 8. With regard to
25 this phase separation layer 9, the layer same as what was mentioned above about the first embodiment can be used. That is, by providing

such a phase separation layer 9, a current narrowing effect is acquired by the phase separation structure formed by mechanisms, such as spinodal decomposition and GP zone formation.

【 0 1 1 0 】

5 Thus, if the phase separation layer 9 is provided between the electrode 8 which adjoins the magnetically free layer 6 and the magnetically free layer 6, the current which flows from the electrode to the magnetically free layer 6 is appropriately narrowed, and the element resistance is made moderately high, and thus, a big
10 magnetoresistance change can be obtained.

【 0 1 1 1 】

In the invention, the first embodiment through the third embodiment may be combined appropriately. That is, the phase separation layer 9 may be provided between the magnetically pinned
15 layer 4 and the magnetically free layer 6 as mentioned above about the first embodiment, the magnetic coupling interception layer 5A may be provided as mentioned above about the second embodiment, and the phase separation layer 9 may be provided between the electrode which adjoins the magnetically free layer and the
20 magnetically free layer as the third embodiment.

【 0 1 1 2 】

Then, it is possible to make each current narrowing effect multiply and to obtain still higher element resistance and the change of magnetoresistance.

25 【 0 1 1 3 】

In the above, the first through third embodiments of the

invention have been explained.

【 0 1 1 4 】

The magnetoresistance effect of the present invention will now be described in more detail referring to the examples.

5 【 0 1 1 5 】

(First example)

First, the magnetoresistance effect elements formed as a first example of the invention using the spinodal decomposition of aluminum (Al)-silver (Ag) system will be explained.

10 【 0 1 1 6 】

In this example, the magnetoresistance effect elements as shown in FIG. 1 were manufactured. And oxidization process was performed to the AlAg alloy as a phase separation layer 9.

The thickness and material of each layer which constitutes the magnetoresistance effect elements of this example are as the following:

Si (1) / 5nm Ta (2) / 200nm Cu (2) / 10nm PtMn (3) / 3nm CoFe (4) / 0.2nm Cu (5A) / 0.8nm AlAg (9) / 0.2nm Cu (5B) / 3nm CoFe (6) / 2nm Ta (7) / 200nm Cu (8).

20 In the above, the reference numerals expressed in FIG. 1 are given to the each corresponding layer with parenthesis.

AlAg used for the base material of the phase separation layer 9 is expressed by the formula $\text{Al}_{100-x}\text{Ag}_x$ where the composition x was set to 0, 5, 10, 20, and 40 atomic %.

25 【 0 1 1 7 】

DC magnetron sputtering method was used as the method to

form films. In the deposition process, the chamber was evacuated at down to a background pressure below 10^{-5} Pa (Pascal), and the deposition was performed at the rate of 0.02-0.1 nm per second. The upper electrode 8 was made into substantially round shape whose diameter was 1 micrometer.

The oxidization process was performed by irradiating an oxygen radical after the film forming process of the phase separation layer 9. Further, a heat treatment was performed at 270 degrees centigrade for 10 hours under the environment where a magnetic field of 5 kOe (oersted) was applied.

【 0 1 1 8 】

On the other hand, as comparative samples, Cu film of 3nm thick was used instead of the AlAg alloy as the material of the phase separation layer 9.

15 【 0 1 1 9 】

The following results were obtained when the magnetoresistance effect MR and the area resistance RA of the magnetoresistance effect element of this example using $\text{Al}_{90}\text{Ag}_{10}$ ($x=10$) and a comparative sample were measured:

20

TABLE 2

| Material of the phase separation layer 9 | MR, % | RA, $\Omega\mu\text{m}^2$ |
|---|----------|------------------------------|
| Cu | 0.5 | 0.08 |
| $\text{Al}_{90}\text{Ag}_{10}$ (with oxidization process) | 6.0 | 0.25 |

For the samples using $\text{Al}_{90}\text{Ag}_{10}$ alloy as the base material of the phase separation layer 9, the crystallinity was investigated, respectively by a cross-sectional TEM (transmission electron microscopy) observation.

5 【 0 1 2 0 】

FIGs. 9A and B are the figures showing the typical schematic diagram of a cross-sectional TEM image and the profile of the elemental analysis by nano-EDX for the sample with oxidization process as mentioned above.

10 【 0 1 2 1 】

In the case of the sample without oxidization process, spinodal decomposition into a separated structure including an aluminum phase and a silver phase of about 1.5 nm width was observed indefinitely. On the other hand, in the case of the sample with oxidization process, as shown also in FIGs. 9A and 9B, the phase separation into an aluminum phase of 9nm width and a silver phase of 1.5nm width by the spinodal decomposition was clearly seen. Further, as a result of performing oxygen analysis for each phase, it was also confirmed that almost all oxygen existed in the aluminum phase.

20 【 0 1 2 2 】

Thus, it was confirmed that the phase separation layer was divided into Ag-rich phase D2 (region 9B) with high conductivity and Al-rich oxide insulating phase D1 (region 9A) which was made to close to Al_2O_3 by spinodal decomposition and oxidization process. Moreover, it was also seen by plane TEM observation that each phase

was finely distributed within a film plane by spinodal decomposition, and the occupancy area of Ag phase was just over or below about 10 %.

【 0 1 2 3 】

5 On the other hand, when $\text{Al}_{80}\text{Ag}_{20}$ ($x=20$) alloy was used as the base material, the following result was obtained as the magnetoresistance effect MR and area resistance RA after performing oxidization process:

TABLE 3

| Material of | MR, | RA, |
|--|-----|-----------------------|
| the phase separation layer 9 | % | $\Omega\mu\text{m}^2$ |
| 10 $\text{Al}_{80}\text{Ag}_{20}$ (with oxidation process) | 4.5 | 0.17 |

In the case of the AlAg alloy, if the silver content is less than 1%, since the area of the high electric conduction phase is too small, the resistance RA per 1 square micrometer will increase to $1\Omega\mu\text{m}^2$, and an increase of noise and a decrease of the frequency response will arise resulting from the high resistance nature like the case of TMR.

On the other hand, if the composition of Ag exceeds 40 %, since the region of a high electric conduction phase becomes too large, the current narrowing effect will not be acquired any longer, but the low R and low AR same as the case where metal intermediate layers, such as Cu, are used will arise.

As for the composition x, it is desirable that it is in a range between 1-40 atomic %Ag, and the optimum composition can be

determined appropriately according to the magnetoresistance effect MR and resistance R which are needed.

The inventors have investigated the case where magnesium (Mg), silicon (Si) and manganese (Mn) are used instead of aluminum (Al) for the alloy used for the base material. As a result, although
5 some differences were seen at MR and R, the same tendency as the case of aluminum was seen in the result and the texture in cross-sectional TEM observation.

【 0 1 2 4 】

10 Furthermore, as illustrated in FIG. 10, in the case where the phase separation layer has a combination of the Al-Ag alloy phase separation layer and the phase separation layer formed from the base material of Cr-Cu alloy, Ag contained in the Al-Ag alloy and Cu contained in the Cr-Cu alloy had a act of current path, and the same
15 effect was acquired.

【 0 1 2 5 】

(Second example)

Next, the magnetoresistance effect elements using the spinodal decomposition of aluminum (Al)-gold (Au) system will be
20 explained as the second example of the invention.

【 0 1 2 6 】

Also in this example, the magnetoresistance effect elements shown in FIG. 1 were fabricated. However, the magnetically pinned layer 4 was made into the so-called "synthetic structure" in this
25 example.

【 0 1 2 7 】

Moreover, the manufacturing method of this example is almost the same as that mentioned above about the first example. However, the phase separation layer 9 was formed, irradiating the ion beam containing oxygen ion on a substrate simultaneously with
5 films formation.

The thickness and material of each layer which constitutes the magnetoresistance effect element are as the following:

Si substrate (1) / 5nm Ta (2) / 200nm Cu (2) / 5nm
(Ni₈₀Fe₂₀)₇₈Cr₂₂ (2) / 10nm PtMn (3) / 2.5nm CoFe(4) / 0.9nm Ru (4)
10 / 2.5nm CoFe (4) / 0.2nm Cu (5A) / 0.8nm AlAu (9) / 0.2nm Cu (5B)
/ 3nm CoFe (6) / 2nm Ta (7) / 200nm Cu (8).

In the above, the reference numerals expressed in FIG. 1 are given to the each corresponding layer with parenthesis.

AlAu used for the base material of the phase separation layer
15 9 is expressed by the formula Al_{100-x}Au_x where the composition x was set to 0, 5, 10, 20, and 40 atomic %.

When Al₉₀Au₁₀ (x=10) alloy was used as the base material, the following result was obtained as the magnetoresistance effect MR and area resistance RA after performing oxidization process:

20

TABLE 4

| Material of the phase separation layer 9 | MR, % | RA, $\Omega\mu\text{m}^2$ |
|--|----------|------------------------------|
| Al ₉₀ Au ₁₀ (with oxidation process) | 7.5 | 0.18 |

As a result of a cross-sectional TEM observation, in the case of

the sample without oxidization process, spinodal decomposition into a separated structure including an aluminum phase and a gold phase of about 1.5 nm width was observed indefinitely. On the other hand, in the case of the sample with oxidization process the phase separation into an aluminum phase and a gold phase of 1.5 nm width by the spinodal decomposition was clearly seen. Further, as a result of performing oxygen analysis for each phase, it was also confirmed that almost all oxygen existed in the aluminum phase.

【 0 1 2 8 】

Thus, it was confirmed that the phase separation layer was divided into Au-rich phase (region 9B) with high conductivity and Al-rich oxide insulating phase (region 9A) which was made to close to Al_2O_3 by spinodal decomposition and oxidization process. Moreover, it was also seen by plane TEM observation that each phase was finely distributed within a film plane by spinodal decomposition, and the occupancy area of Ag phase was just over or below about 10 %.

【 0 1 2 9 】

On the other hand, when $\text{Al}_{80}\text{Au}_{20}$ ($x=20$) alloy was used as the base material, the following result was obtained as the magnetoresistance effect MR and area resistance RA after performing oxidization process:

TABLE 5

| Material of the phase separation layer 9 | MR, % | RA, $\Omega\mu\text{m}^2$ |
|---|----------|------------------------------|
| $\text{Al}_{80}\text{Au}_{20}$ (with oxidization process) | 5.5 | 0.13 |

In the case of the AlAu alloy, if the gold content is less than 1%, since the area of the high electric conduction phase is too small, the resistance RA per 1 square micrometer will increase to $1\ \Omega\mu\text{m}^2$, and
5 an increase of noise and a decrease of the frequency response will arise resulting from the high resistance nature like the case of TMR.

On the other hand, if the composition of Au exceeds 40 %, since the region of a high electric conduction phase becomes too large, the current narrowing effect will not be acquired any longer,
10 but the low R and low AR same as the case where metal intermediate layers, such as Cu, are used will arise.

As for the composition x, it is desirable that it is in a range between 1-40 atomic %Au, and the optimum composition can be determined appropriately according to the magnetoresistance effect
15 MR and resistance R which are needed.

【 0 1 3 0 】

The inventors have investigated the case where magnesium (Mg), calcium (Ca), silicon (Si), germanium (Ge), boron (B), tantalum (Ta), tungsten (W), niobium (Nb), zirconium (Zr), titan (Ti),
20 chromium (Cr), zinc (Zn), lithium (Li) and gallium (Ga) are used instead of aluminum (Al) for the alloy used for the base material.

【 0 1 3 1 】

As a result, although some differences were seen at MR and R, the same tendency as the case of aluminum was seen in the result
25 and the texture in cross-sectional TEM observation.

【 0 1 3 2 】

(Third example)

Next, the magnetoresistance effect elements using the spinodal decomposition of copper (Cu)-nickel (Ni)-iron (Fe) system
5 will be explained as the third example of the invention.

【 0 1 3 3 】

Also in this example, the magnetoresistance effect elements shown in FIG. 1 were fabricated. However, the interface adjusting layer 5B was not provided, and the magnetically pinned layer 4 was
10 made into the so-called "synthetic structure" in this example.

【 0 1 3 4 】

The thickness and material of each layer which constitutes the magnetoresistance effect element are as the following:

Si substrate (1) / 5nm Ta (2) / 200nm Cu (2) / 5nm
15 (Ni₈₀Fe₂₀)₇₈Cr₂₂ (2) / 10nm PtMn (3) / 2.5nm CoFe (4) / 0.9nm Ru (4)
/ 2.5nm CoFe (4) / 0.8nm CuNiFe (9) / 2.0nm Cu (5) / 3nm CoFe (6)
/ 2nm Ta (7) / 200nm Cu (8).

In the above, the reference numerals expressed in FIG. 12 are given to the each corresponding layer with parenthesis.

20 CuNiFe alloy used for the base material of the phase separation layer 9 is expressed by the formula $\text{Cu}_x(\text{Ni}_{100-y}\text{Fe}_y)_{100-x}$ where the composition x was set to 0.5, 1, 10, 20, 50 and 60 atomic % and the composition y was set to 0, 20, 50 and 70, respectively.

25 The magnetic coupling interception layer 5 which consists of 2.0 nm Cu was inserted between the phase separation layer 9 and

the magnetization free layer 6. The thickness of the layer 5 is needed to be enough to intercept the magnetic coupling between the phase separation layers 9 which consist of the CuNiFe alloy and the magnetization free layers 6, and is desirably in a range between 1
5 and 3nm.

【 0 1 3 5 】

The phase separation layer 9 was formed, irradiating the ion beam containing oxygen ion on a substrate simultaneously with films formation.

10 【 0 1 3 6 】

For comparison, the magnetoresistance effect elements which include the alloy layer of $\text{Cu}_{20}(\text{Ni}_{80}\text{Fe}_{20})_{80}$ (atomic %) was also fabricated instead of the phase separation layer 9 of the example.

【 0 1 3 7 】

15 After formation of the elements, magnetic field of 5 kOe was applied in the vacuum, and heat treatment of 10 hours was carried out at 300 degrees centigrade.

【 0 1 3 8 】

The magnetoresistance effect MR of the magnetoresistance
20 effect element of this example was 3 – 10 %, and the resistance R was 0.15-1.0 ohms except the case where composition x was set to 0.1 and 60, and composition y was set to 0.7. Thus, the good characteristics were obtained. On the other hand, in the case of the magnetoresistance effect elements where composition x was set to 5
25 and 60, and composition y was set to 70, it turned out that the MR was 0.5 % or less, and the ΔR was also very small, and thus, they

were not good for a practical use.

The inventors have investigated the cases where Au, Ag, Pt, Pd, Ir and Os were used respectively as a material of the magnetic interception layer 5 in stead of Cu, and have found that the almost
5 same magnetic interception effect was obtained.

【 0 1 3 9 】

Moreover, on the other hand, in this example, it also turned out that degradation of the characteristic of a magnetoresistance effect element is hardly seen, even if the magnetization pinned layer
10 4 was oxidized a little.

【 0 1 4 0 】

On the other hand, in the case of the comparative magnetoresistance effect element which does not include the magnetic coupling interception layer 5, the magnetic field response
15 of the magnetization free layer 6 was degraded under the influence of the phase separation layer 9 which had some magnetism, and therefore MR sensitivity fell.

【 0 1 4 1 】

The above results show that it becomes possible to offer the
20 magnetoresistance effect element of the good characteristic by using the alloy of the composition region which realizes the spinodal decomposition and the oxidation of the Ni-Fe phase as the base material of the phase separation layer 9, and by providing the magnetic coupling interception layer 5.

25 【 0 1 4 2 】

Furthermore, the inventors have used the alloy system where

Fe is replaced by Co in the above-mentioned formula and have obtained the similar results. That is, the magnetoresistance effect elements using the alloy system of the composition formula $\text{Cu}_x(\text{Ni}_{100-y}\text{Co}_y)_{100-x}$ have shown almost the same characteristics as the elements using $\text{Cu}_x(\text{Ni}_{100-y}\text{Fe}_y)_{100-x}$.

【 0 1 4 3 】

Furthermore, the same effect was acquired in the case where the phase separation layer was made by combining the $\text{Cu}_x(\text{Ni}_{100-y}\text{Fe}_y)_{100-x}$ phase separation layer and the phase separation layer using the Al-Ag alloy as a base material, as illustrated in FIG. 10.

【 0 1 4 4 】

(Fourth example)

Next, the magnetoresistance effect element which comprises two phase separation layers will be explained as a fourth example of the invention.

【 0 1 4 5 】

FIGs. 12 and 13 are schematic diagrams showing the cross-sectional structure of the magnetoresistance effect elements of this example. The same reference numerals are given to the same elements as what were mentioned above about FIG. 1 through FIG. 11 also about these figures, and detailed explanation is omitted.

【 0 1 4 6 】

That is, in the structure of FIG. 12, the phase separation layer 9 is inserted not only the portion of a spacer layer but in the magnetization pinned layer 4.

【 0 1 4 7 】

Moreover, in the structure of FIG. 13, the phase separation layer 9 is inserted not only the portion of a spacer layer but in the magnetization free layer 6.

【 0 1 4 8 】

5 The magnetoresistance effect elements of this example were fabricated by the methods almost same as the method mentioned above about the first example.

 The thickness and material of each layer which constitutes the magnetoresistance effect element shown in FIG. 12 are as the
10 following:

 Si substrate (1) / 5 nm Ta (2) / 200nm Cu (2) / 5nm
(Ni₈₀Fe₂₀)₇₈Cr₂₂ (2) / 10nm PtMn (3) / 2nm CoFe (4) / 0.5nm CuNiFe
(9) / 2.5nm CoFe (4) / 0.5nm Cu (5) / 0.8nm CuNiFe (9) / 3nm CoFe
(6) / 2nm Ta (7) / 200nm Cu (8).

15 In the above, the reference numerals expressed in FIG. 13 are given to the each corresponding layer with parenthesis.

 The thickness and material of each layer which constitutes the magnetoresistance effect element shown in FIG. 13 are as the following:

20 Si substrate (1) / 5 nm Ta (2) / 200nm Cu (2) / 5nm
(Ni₈₀Fe₂₀)₇₈Cr₂₂ (2) / 10nm PtMn (3) / 4nm CoFe (4) / 0.2nm Cu(5) /
0.8nm CuNiFe (9) / 1nm Cu (5) / 1nm CoFe (6) / 0.3nm AlAg (9) /
3nm NiFe (6) / 2nm Ta (7) / 200nm Cu (8).

 In the above, the reference numerals expressed in FIG. 13 are
25 given to the each corresponding layer with parenthesis.

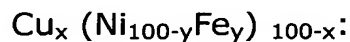
 These magnetoresistance effect elements were fabricated by

the methods almost same as the method mentioned above about the first example.

However, after the film forming process, the magnetic phase separation layer 9 between the magnetization pinned layer 4 and the magnetization free layer 6 was oxidized by irradiating an ion beam containing oxygen ion. In contrast, the phase separation layer 9 inserted into the magnetization pinned layer 4 or the magnetization free layer 6 was formed by irradiating the ion beam which contained oxygen ion simultaneously with the film forming.

10 【 0 1 4 9 】

CuNiFe which is the base material of the phase separation layer 9 is expressed by the following composition formula:



where composition x was set to 1, 10, 20 and 50, and composition y was set to 0, 0.2 and 0.5. The AlAg alloy was Al₉₀Ag₁₀ (atomic %).

15 【 0 1 5 0 】

After the sample formation, a magnetic field of 5 kOe was applied in a vacuum, and a heat treatment of 10 hours was carried out at 300 degrees centigrade.

20 【 0 1 5 1 】

Thus, as a result of evaluating the characteristic of the fabricated magnetoresistance effect element, the good magnetoresistance change MR and good resistance R comparable as the third example were obtained. Moreover, the comparable good characteristics were acquired with both the structure of FIG. 12 and the structure of FIG. 13.

【 0 1 5 2 】

On the other hand, when $\text{Al}_{90}\text{Au}_{10}$ was used as the base material of the phase separation layer 9, the same good characteristic was also acquired.

5 【 0 1 5 3 】

(The fifth example)

Next, the magnetoresistance effect element where the first embodiment and the second embodiment are combined will be explained as the fifth example of the invention.

10 【 0 1 5 4 】

FIG. 14 is a schematic diagram showing the cross-sectional structure of the magnetoresistance effect element of this example. The same reference numerals are given to the same elements as what were mentioned above about FIG. 1 through FIG. 13 also about
15 this figure, and detailed explanation is omitted.

【 0 1 5 5 】

That is, the structure of this example has the laminated structure of the so-called "top-type" where the magnetization free layer 6 is provided in the bottom side when seen from the substrate
20 electrode 1. And in this laminated structure, the phase separation layers 9-3 and 9-4 are provided in the portion of the spacer layer, and the phase separation layers 9-1 and 9-2 are inserted between the electrode 1 and magnetization free layer 6.

【 0 1 5 6 】

25 The thickness and material of each layer which constitute the magnetoresistance effect element of this example are as the

following:

Si substrate (1) / 3nm Ta (2) / 200nm Cu (2) / 2nm Al₇₀Ag₃₀
(9-1) / 0.8nm Cr₈₀Cu₂₀ (9-2) / 4nm Co₉₀Fe₁₀ (6) / 1nm Al₇₀Cu₃₀ (9-3)
/ 1nm Cu₂₀Ni₄₀Co₂₀ (9-4) / 0.5nm Cu (5) / 4nm Co₉₀Fe₁₀ (4) / 15nm
5 PtMn (3) / 2nm Ru (7) / 200nm Cu (8).

In the above, the reference numerals expressed in FIG. 14 are
given to the each corresponding layer with parenthesis.

These magnetoresistance effect elements of this example
were fabricated by the methods almost same as the method
10 mentioned above about the first example. As the oxidization process
for the phase separation layers 9-1, 9-2, and 9-3, after forming the
base material film, the oxygen of flux of 4 sccm was made into the
oxygen radical using 50 watts (W) of RF, and was irradiated for about
30 seconds with a beam energy of 100 volts (V) of accelerating
15 voltage.

With regard to the CuNiCo alloy of the phase separation layer
9-4, after promoting the spinodal decomposition by Ar ion irradiation
of low energy after depositing the base material, an oxidation
process was carried out by the same method as what was mentioned
20 above while setting the RF power at 70 W.

【 0 1 5 7 】

The area resistance per 1 square micron area was 350 (mΩ ·
μm²) and the magnetoresistance rate of change of the magnetic
characteristic after a heat treatment of the magnetoresistance effect
25 element of this example was 5.5 %. That is, the good characteristic
was acquired and it was confirmed that the magnetoresistance effect

element applicable to the actual magnetic head has been formed.

【 0 1 5 8 】

(The sixth example)

Next, the magnetoresistance effect element where the first
5 embodiment and the second embodiment are combined like the fifth
example will be explained as the sixth example of the invention.

【 0 1 5 9 】

FIG. 15 is a schematic diagram showing the cross-sectional
structure of the magnetoresistance effect element of this example.
10 The same reference numerals are given to the same elements as
what were mentioned above about FIG. 1 through FIG. 14 also about
this figure, and detailed explanation is omitted.

【 0 1 6 0 】

That is, the structure of this example has the laminated
15 structure of the so-called "bottom type" where the magnetization
pinned layer 4 is provided in the bottom side, when seen from the
substrate electrode 1. And also in this lamination structure, the
phase separation layers 9-1 and 9-2 are provided in the portion of
the spacer layer, and the phase separation layers 9-3 and 9-4 are
20 inserted also between the magnetization free layer 6 and the
electrode 8.

【 0 1 6 1 】

The thickness and material of each layer which constitutes the
magnetoresistance effect element of this example are as the
25 following:

Si substrate (1) / 5nm Ta (2) / 2nm Ru (2) / 15nm PtMn (3) /

4nm $\text{Co}_{90}\text{Fe}_{10}$ (4) / 1nm CuNiFe (9-1) / 0.7nm $\text{Al}_{70}\text{Cu}_{30}$ (9-2) / 0.2nm
Cu (5) / 4nm $\text{Co}_{90}\text{Fe}_{10}$ (6) / 0.5nm $\text{Al}_{80}\text{Au}_{20}$ (9-3) / 1nm $\text{Al}_{70}\text{Cu}_{30}$ (9-4)
/ 200nm Cu (8).

In the above, the reference numerals expressed in FIG. 15 are
5 given to the each corresponding layer with parenthesis.

The magnetoresistance effect elements of this example were
fabricated by the methods almost same as the method mentioned
above about the fifth example.

【 0 1 6 2 】

10 The area resistance per 1 square micron area of the magnetic
characteristic after a heat treatment of the magnetoresistance effect
element of this example was $250 (\text{m}\Omega \cdot \mu\text{m}^2)$, and amount ΔR of area
resistance change per 1 square micron area (which corresponds to
the output of a magnetic head) was $25 (\text{m}\Omega \cdot \mu\text{m}^2)$. That is, a very
15 large amount ΔR of area resistance change was obtained, and it was
confirmed to be sufficiently possible to apply the magnetoresistance
effect element of this example to an actual magnetic head.

【 0 1 6 3 】

(The seventh example)

20 Next, the magnetoresistance effect elements using the
aluminum (Al)-silver (Ag)-tantalum (Ta) system or aluminum
(Al)-copper (Cu) system will be explained as the seventh example of
the invention.

【 0 1 6 4 】

25 In this example, the magnetoresistance effect element having
a basic structure same as the one shown in FIG. 1 was manufactured.

However, the magnetization pinned layer 4 has the so-called "synthetic structure" in this example.

【 0 1 6 5 】

The magnetoresistance effect elements of this example were
5 fabricated by the methods almost same as the method mentioned
above about the first example. However, in the formation process of
the phase separation layer 9, an argon ion of electric power 50 watts
was first irradiated with an accelerating voltage of 50 volts after
forming the film in order to give a phase separation, and an
10 oxidization process was subsequently performed by irradiating an ion
beam which contained oxygen ion. Furthermore, after the
magnetoresistance effect element formation, heat treatment of 270
degrees centigrade for 10 hours in a magnetic field was carried out in
order to improve the magnetic characteristics.

15 The thickness and material of each layer which constitutes a
magnetoresistance effect element are as the following:

Si substrate (1) / 5nm Ta (2) / 200nm Cu (2) / 5nm
(Ni₈₀Fe₂₀)₇₈Cr₂₂ (2) / 10nm PtMn (3) / 3.5nm CoFe (4) / 1.0nm Ru (4)
/ 3.5nm CoFe (4) / 0.2nm Cu (5A) / 1.1nm AlAgTa or AlCu (9) /
20 0.5nmCu (5B) / 3.5nm CoFe (6) / 2nm Ru (7) / 200nm Cu (8).

In the above, the reference numerals expressed in FIG. 1 are
given to the each corresponding layer with parenthesis.

As a base material of the phase separation layer 9,
(Al₈₀Ta₂₀)₈₀Ag₂₀ alloy or Al-Cu alloy was used. In the case of the Al-Cu
25 system, the spinodal decomposition takes place at the composition
of Al₇₀Cu₃₀. However, since copper diffuses from the lower Cu layer

(5A) and the upper Cu layer (5B), the initial composition of copper in the AlCu layer (9) may be made lower than the spinodal composition.

The inventors conducted the experiment in order to investigate the structure of the phase separation layer 9 in relation to this example. First, 0.2nm Cu (5A) / 1.1nm AlAgTa alloy (9) was laminated twice on Si substrate (1) / 5nm Ta (2) / 10nm PtMn (3) / 3.5nm CoFe (4) with the same conditions as the phase separation layer 9 of $(\text{Al}_{80}\text{Ta}_{20})_{80}\text{Ag}_{20}$ alloy.

After performing a heat treatment, the phase separation layer 9 was observed by planar TEM and sectional TEM, and composition and its distribution were investigated by SIMS (secondary ion mass spectroscopy).

【 0 1 6 6 】

As a result, the structure of the phase separation layer 9 was almost the same as the one shown in FIG. 8. Specifically, planar TEM and SIMS showed that silver (Ag) phase 9B (D2) with high purity whose particle diameter is 2-3 nm, oxide insulator phase 9A (D1) having a composition close to Al_2O_3 , and oxide insulating phase 9A (D2) having a composition close to Ta_2O_5 were formed. These separated phases are produced by spinodal decomposition. From the sectional TEM, it was confirmed that the silver (Ag) phase 9B is formed in a pillar shape so that minute current paths were formed in the direction of thickness.

【 0 1 6 7 】

The area resistance per 1 square micron area of the magnetic characteristic after a heat treatment of the magnetoresistance effect

elements of this example was $250 \text{ (m}\Omega \cdot \mu\text{m}^2\text{)}$, and a rate of magnetoresistance change was 6.5 %. It was confirmed to be sufficiently possible to apply the magnetoresistance effect element of this example to an actual magnetic head.

5 【 0 1 6 8 】

(The eighth example)

Next, the magnetic reproducing apparatus which comprises the magnetoresistance effect element of the invention will be explained as the eighth example of the invention.

10 That is, the magnetoresistance effect element or the magnetic head explained with reference to Figs. 1 through 15 can be incorporated in a recording/reproducing magnetic head assembly and mounted in a magnetic reproducing apparatus.

【 0 1 6 9 】

15 Fig. 16 is a perspective view that shows outline configuration of this kind of magnetic reproducing apparatus. The magnetic reproducing apparatus 150 shown here is of a type using a rotary actuator. A magnetic reproducing medium disk 200 is mounted on a spindle 152 and rotated in the arrow A direction by a motor, not
20 shown, which is responsive to a control signal from a controller of a driving mechanism, not shown. The magnetic reproducing apparatus 150 shown here may have a plurality of medium disks 200 inboard.

【 0 1 7 0 】

25 The medium disk 200 may be of a "lateral recording type" in which directions of the recording bits are substantially in parallel to

the disk surface or may be of a "perpendicular recording type" in which directions of the recording bits are substantially perpendicular to the disk surface.

A head slider 153 for carrying out recording and reproduction of information to be stored in the medium disk 200 is attached to the tip of a film-shaped suspension 154. The head slider 153 supports a magnetoresistance effect element or magnetic head, for example, according to one of the foregoing embodiments of the invention, near the distal end thereof.

10 【 0 1 7 1 】

Once the medium disk 200 rotates, the medium-facing surface (ABS) of the head slider 153 is held floating by a predetermined distance above the surface of the medium disk 200. Also acceptable is a so-called "contact-traveling type" in which the slider contacts the medium disk 200.

15 【 0 1 7 2 】

The suspension 154 is connected to one end of an actuator arm 155 having a bobbin portion for holding a drive coil, not shown, and others. At the opposite end of the actuator arm 155, a voice coil motor 156, a kind of linear motor, is provided. The voice coil motor 156 comprises a drive coil, not shown, wound on the bobbin portion of the actuator arm 155, and a magnetic circuit made up of a permanent magnet and an opposed yoke that are opposed to sandwich the drive coil.

20 【 0 1 7 3 】

The actuator arm 155 is supported by ball bearings, not shown,

which are located at upper and lower two positions of the spindle 157 and driven by the voice coil motor 156 for rotating, sliding movements.

【 0 1 7 4 】

5 Fig. 17 is a perspective view of a magnetic head assembly at the distal end from an actuator arm 155 involved, which is viewed from the disk. The magnetic head assembly 160 includes the actuator arm 155 having the bobbin portion supporting the drive coil, for example, and the suspension 154 is connected to one end of the
10 actuator arm 155.

【 0 1 7 5 】

At the distal end of the suspension 154, a head slider 153 carrying the magnetoresistance effect element as explained with reference to figures 1 through 15 is provided. The suspension 154
15 has a lead 164 for writing and reading signals, and the lead line 164 is connected to electrodes of the magnetic head incorporated in the head slider 153. Numeral 165 in Fig. 24 denotes an electrode pad of the magnetic head assembly 160.

【 0 1 7 6 】

20 According to this example, one of the magnetoresistance effect elements already explained in conjunction with the aforementioned embodiments is used as the magnetoresistance effect element, information magnetically recorded on the medium disk 200 under a higher recording density than before can be read
25 reliably.

【 0 1 7 7 】

(ninth Example)

Next, a magnetic memory having the magnetoresistance effect element of the embodiment will be explained as the ninth example of the invention. That is, a magnetic memory, such as a magnetic random access memory (MRAM), where memory cells are
5 arranged in the shape of a matrix can be realized by using the magnetoresistance effect element of the embodiment.

【 0 1 7 8 】

Fig. 18 is a conceptual diagram which exemplifies the matrix
10 structure of the magnetic memory of the embodiment.

【 0 1 7 9 】

That is, this figure shows the circuit structure of the embodiment in the case of having arranged the memory cells each of which includes a magnetoresistance effect element mentioned above
15 with reference to Figs. 1 through 15, in the shape of a matrix array.

In order to choose one bit in an array, it has the sequence decoder 350 and the line decoder 351. By selecting the bit line 334 and the word line 332, specific switching transistor 330 is turned on and a specific cell is chosen uniquely. And the bit information
20 recorded on the magnetic-recording layer which constitutes the magnetoresistance effect element 321 can be read by detecting with a sense amplifier 352.

【 0 1 8 0 】

When writing in bit information, writing current is passed in
25 the specific write-in word line 323 and the specific bit line 322, respectively, and the current magnetic field is applied to the

recording layer of a specific cell.

【 0 1 8 1 】

Fig. 19 is a conceptual diagram showing another example of the matrix structure of the magnetic memory of the embodiment. That is, in the case of this example, the bit lines 322 and word lines 334 which were wired in the shape of a matrix are chosen by decoders 360 and 361, respectively, and the specific memory cell in an array is chosen uniquely.

Each memory cell has the structure where Diode D is connected with the magnetoresistance effect element 321 in series. Here, Diode D has the role to prevent that sense current detours in memory cells other than magnetoresistance effect element 321 selected.

【 0 1 8 2 】

In writing, write-in current is passed in a specific bit line 322 and a word line 323, thereby applying the current magnetic field to the recording layer of a specific cell.

【 0 1 8 3 】

Fig. 20 is a conceptual diagram showing a principal part of the cross sectional structure of a magnetic memory according to an embodiment of the invention.

And Fig. 21 shows the A-A' line sectional view.

【 0 1 8 4 】

That is, the structure shown in these figures corresponds to the memory cell of the 1-bit portion of the magnetic memory which operates as a random access memory.

This memory cell consists of a storage cell portion 311 and a transistor portion 312 for address selection.

【 0 1 8 5 】

The storage cell portion 311 has the magnetoresistance effect
5 element 321 and a pair of wiring 322 and 324 connected to the
element 321. The magnetoresistance effect element 321 has a
structure mentioned with reference to Figs. 1 through 15, and shows
a large magnetoresistance effect.

【 0 1 8 6 】

10 What is necessary is to pass sense current for the
magnetoresistance effect element 321 in the case of bit information
read-out, and just to detect the resistance change. In addition, the
magnetization free layer of the magnetoresistance effect element
can be used as the magnetic recording layer.

15 【 0 1 8 7 】

A selecting transistor 330 connected through a via 326 and
buried wiring 328 is formed in a transistor portion 312 for selection.
This transistor 330 carries out switching operation according to the
voltage applied to a gate 332, and controls switching of the current
20 path between the magnetoresistance effect element 321 and wiring
334.

【 0 1 8 8 】

Moreover, under the magnetoresistance effect element, the
write-in wiring 323 is formed in the direction which intersects the
25 wiring 322. These write-in wirings 322 and 323 can be formed with
the alloy containing aluminum (Al), copper (Cu), tungsten (W),

tantalum (Ta), or one of these.

【 0 1 8 9 】

In a memory cell of such structure, when writing bit information in the magnetoresistance effect element 321, a write-in
5 pulse current is passed to the wirings 322 and 323. Then, a synthetic magnetic field induced by these current is applied to a record layer, and magnetization of a record layer of the magnetoresistance effect element can be reversed suitably.

【 0 1 9 0 】

10 On the other hand, when reading bit information, sense current is passed through wiring 322, the magnetoresistance element 321 containing a magnetic-recording layer, and the lower electrode 324, and a change of the resistance of the magnetoresistance effect element 321 or resistance itself is
15 measured.

【 0 1 9 1 】

By using the magnetoresistance effect element mentioned with reference to Figs. 1 through 15, a large magnetoresistance effect is obtained. Therefore, a stable read-out can be performed
20 even if the cell size is reduced to realize a large capacity storage.

【 0 1 9 2 】

Heretofore, embodiments of the invention have been explained in detail with reference to some specific examples. The invention, however, is not limited to these specific examples.

25 For example, material, shape and thickness of the ferromagnetic layer, anti-ferromagnetic layer, insulating film and

ferromagnetic film of the magnetoresistance effect element according to the invention may be appropriately selected by those skilled in the art within the known techniques to carry out the invention as taught in the specification and obtain equivalent effects.

5 【 0 1 9 3 】

Further, in a case where the magnetoresistance effect element of the invention is applied to a magnetic head, by providing magnetic shields on upper and lower side of the element, the reproducing resolution can be regulated.

10 【 0 1 9 4 】

It will be also appreciated that the invention is applicable not only to optically-assisted magnetic heads or magnetic recording apparatuses of the lengthwise recording type but also to those of the perpendicular magnetic recording type and ensures substantially the same effects.

15 【 0 1 9 5 】

Further, the magnetic reproducing apparatus according to the present invention may be of a fixed type in which specific magnetic recording medium is permanently installed, while it may be of a removable type in which the magnetic recording medium can be replaced easily.

20 【 0 1 9 6 】

Further, also concerning the magnetic memory according to the invention, those skilled in the art will be able to carry out the invention by appropriately selecting a material or a structure within the known techniques.

While the present invention has been disclosed in terms of the embodiment in order to facilitate better understanding thereof, it should be appreciated that the invention can be embodied in various ways without departing from the principle of the invention.
5 Therefore, the invention should be understood to include all possible embodiments and modification to the shown embodiments which can be embodied without departing from the principle of the invention as set forth in the appended claims.

【Effect of the invention】

10 【 0 1 9 7 】

According to the invention, it becomes possible to make the substantial element size smaller effectually and to enlarge the big amount of resistance change by providing the phase separation layer having unique structure and narrowing down the sense current.

15 【 0 1 9 8 】

On the other hand, it also becomes possible to intercept the magnetic coupling certainly by providing the magnetic coupling interception layer, and to improve magnetic characteristic of the magnetic layer by making the magnetic coupling interception layer
20 act as a buffer layer.

【 0 1 9 9 】

As a result, it becomes possible to provide the magnetoresistance effect element which has the big amount of resistance change and suitable resistance. The HDD having a high
25 magnetic storage density and the magnetic memory can be realized by using the magnetoresistance effect element for the

magnetoresistance head.

【Brief description of the drawings】

【Fig.1】

FIG. 1 is a schematic diagram showing the cross-sectional
5 structure of the magnetoresistance effect element according to the
first embodiment of the present invention.

【Fig.2】

FIG. 2 is a diagram which illustrating a state that the phase
separation layer 9 narrows down the sense current.

10 **【Fig.3】**

FIG. 3 is a schematic diagram showing the example of the
superficial composition of the phase separation layer 9.

【Fig.4】

FIG. 4 is a flow chart showing a part of formation process of
15 the phase separation layer 9 in the embodiment of the present
invention.

【Fig.5】

FIGs. 5A through 5C are schematic diagrams which illustrate
the change of the planar structure of the phase separation layer 9.

20 **【Fig.6】**

FIG. 6 is a flow chart showing the other method of forming the
phase separation layer 9.

【Fig.7】

FIG. 7 is a schematic sectional view showing the example of

the phase separation in two or more kinds of solid phases depending on the composition element which forms the base material.

【Fig.8】

FIG.8 is the schematic diagram which expresses the method
5 of irradiating an ion beam as a separating process S2 which produces spinodal decomposition.

【Fig.9】

FIG. 9A is a schematic diagram of the TEM image of the
section of the phase separation layer which is phase-separated with
10 the base material of $\text{Al}_{90}\text{Ag}_{10}$ alloy and is oxidized.

FIG. 9B is a schematic diagram showing the profile of the
elemental analysis by nano-EDX (Energy Dispersive X-ray
photoelectron spectroscopy) of the phase separation layer.

【Fig.10】

FIG. 10 is a schematic diagram which illustrates the
15 cross-sectional structure of the phase separation layer 9 which has lamination structure.

【Fig.11】

FIG. .11 is a schematic diagram which illustrates the
20 cross-sectional structure of the magnetoresistance effect element according to the embodiment of the invention.

【Fig.12】

FIG. 12 is schematic diagram showing the cross-sectional
structure of the magnetoresistance effect element of the example of
25 the invention.

【Fig.13】

FIG. 13 is schematic diagram showing the cross-sectional structure of the magnetoresistance effect element of the example of the invention.

5 **【Fig.14】**

FIG. 14 is schematic diagram showing the cross-sectional structure of the magnetoresistance effect element of the example of the invention.

【Fig.15】

10 FIG. 15 is schematic diagram showing the cross-sectional structure of the magnetoresistance effect element of the example of the invention.

【Fig.16】

15 FIG.16 is the principal part perspective diagram which illustrates the outline structure of the magnetic reproducing apparatus of the embodiment of the present invention.

【Fig.17】

20 Fig. 17 is a perspective view of a magnetic head assembly at the distal end from an actuator arm 155 involved, which is viewed from the disk.

【Fig.18】

FIG.18 is the schematic diagram which illustrates the matrix structure of the magnetic memory of the embodiment of the present invention.

【Fig.19】

FIG.19 is a schematic diagram showing the other example of the matrix structure of the magnetic memory of the embodiment of the present invention.

5 【Fig.20】

FIG.20 is a schematic diagram showing the principal part section structure of the magnetic memory according to the embodiment of the present invention.

【Fig.21】

10 FIG.21 is the A-A' line sectional view of FIG. 20.

【Fig.22】

FIG.22 is the schematic diagram which illustrates the outline section structure of the spin valve film.

【Explanations of letters or numerals】

- 15 1 substrate electrode
 2 base layer
 3 antiferromagnetic layer
 4 magnetically fixed layer (pinned layer)
 5、 5 A magnetic coupling interception layer
20 5 B interface adjustment layer
 6 magnetically free layer (free layer)
 7 protective layer
 8 upper electrode layer
 9 phase separation layer
25 1 0 intermediate layer (spacer layer)

1 5 0 magnetic reproducing apparatus
1 5 2 spindle
1 5 3 head slider
1 5 4 suspension
5 1 5 5 actuator arm
1 5 6 voice coil motor
1 5 7 spindle
1 6 0 magnetic head assembly
1 6 4 lead
10 2 0 0 medium disk
3 1 1 storage cell portion
3 1 2 transistor portion
3 2 1 magnetoresistance effect element
3 2 2 bit line
15 3 2 3 word line
3 2 4 lower electrode
3 2 6 via
3 2 8 wiring
3 3 0 transistor
20 3 3 2 word line
3 3 4 bit line
3 5 0 sequence decoder
3 5 1 line decoder
3 5 2 sense amplifier
25 3 6 0 decode

【Name of Document】 ABSTRACT

【Abstract】

【Problem】 The purpose of the invention is to provide the practical magnetoresistance effect element which has suitable resistance and the big amount of MR change, and serves as high sensitivity magnetically.

【Problem】 A magnetoresistance effect element comprising: a magnetoresistance effect film including a first ferromagnetic layer (4) whose direction of magnetization is pinned substantially in one direction, a second ferromagnetic layer (6) whose direction of magnetization changes in response to an external magnetic field, and an intermediate layer provided between the first and second ferromagnetic layers; a pair of electrodes electrically coupled to the magnetoresistance effect film and configured to supply a sense current perpendicularly to a film plane of the magnetoresistance effect film; and a phase separation layer (9) provided between the pair of electrodes, the phase separation layer comprising a first phase (9A) and a second phase (9B) formed by a phase separation in a solid phase from an alloy including a plurality of elements, one of the first and second phases including at least one element selected from the group consisting of oxygen, nitrogen, fluorine and carbon in higher concentration than other of the first and second phases is provided.

【Chosen Drawing】 Fig. 1



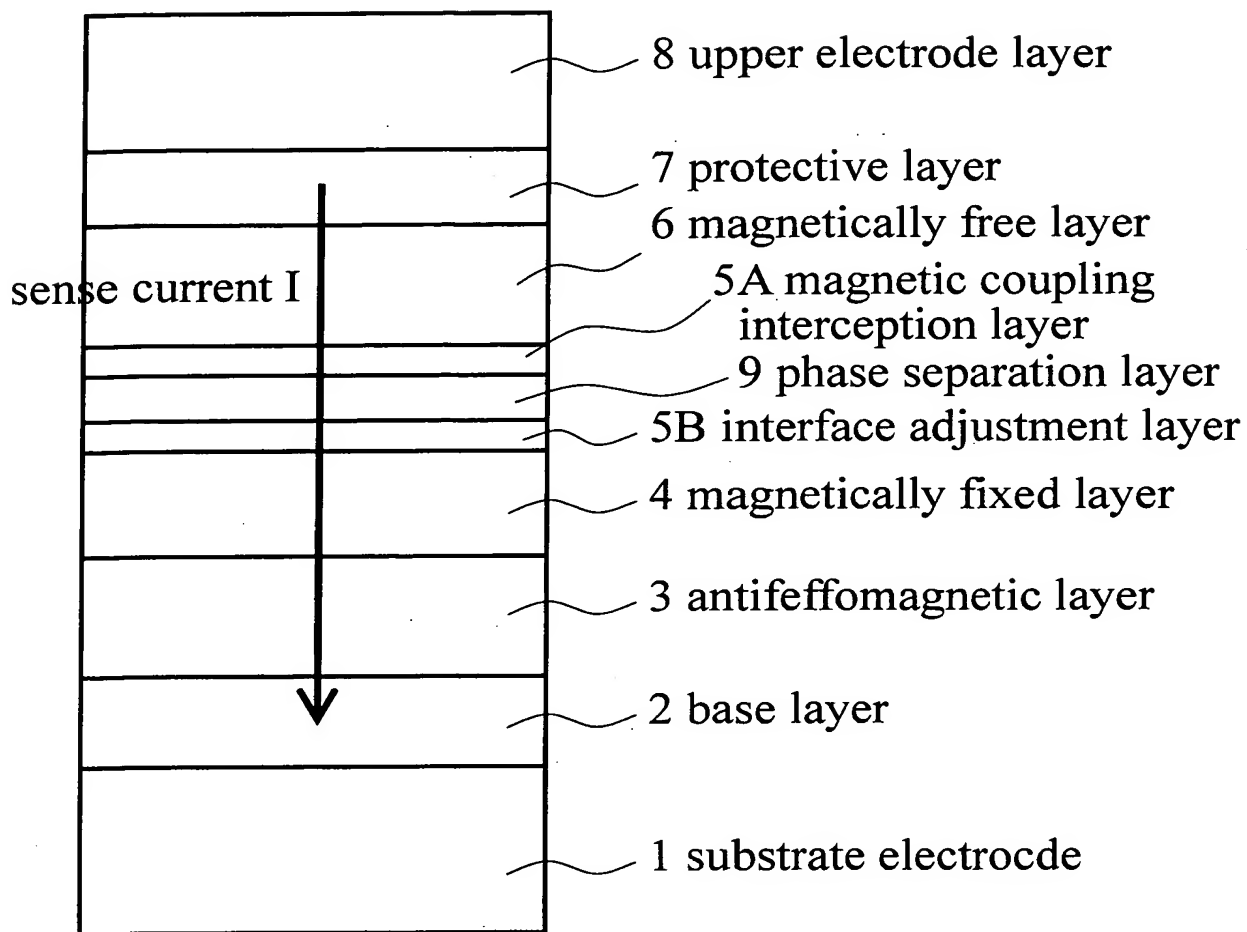
Filed on September 11, 2002

Japanese Patent Application No. 2002-265883

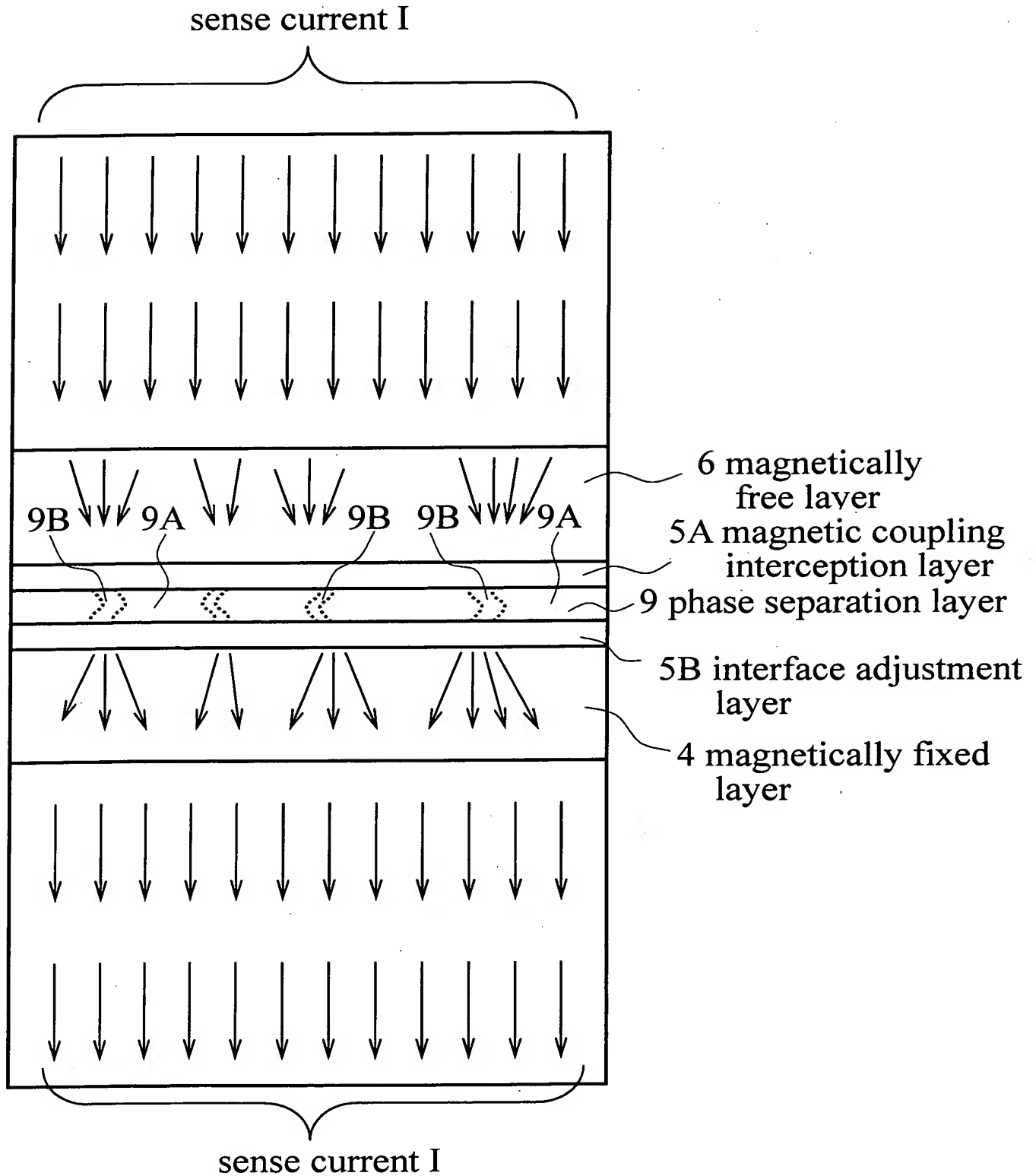
1/17

【Name of Documents】 DRAWINGS

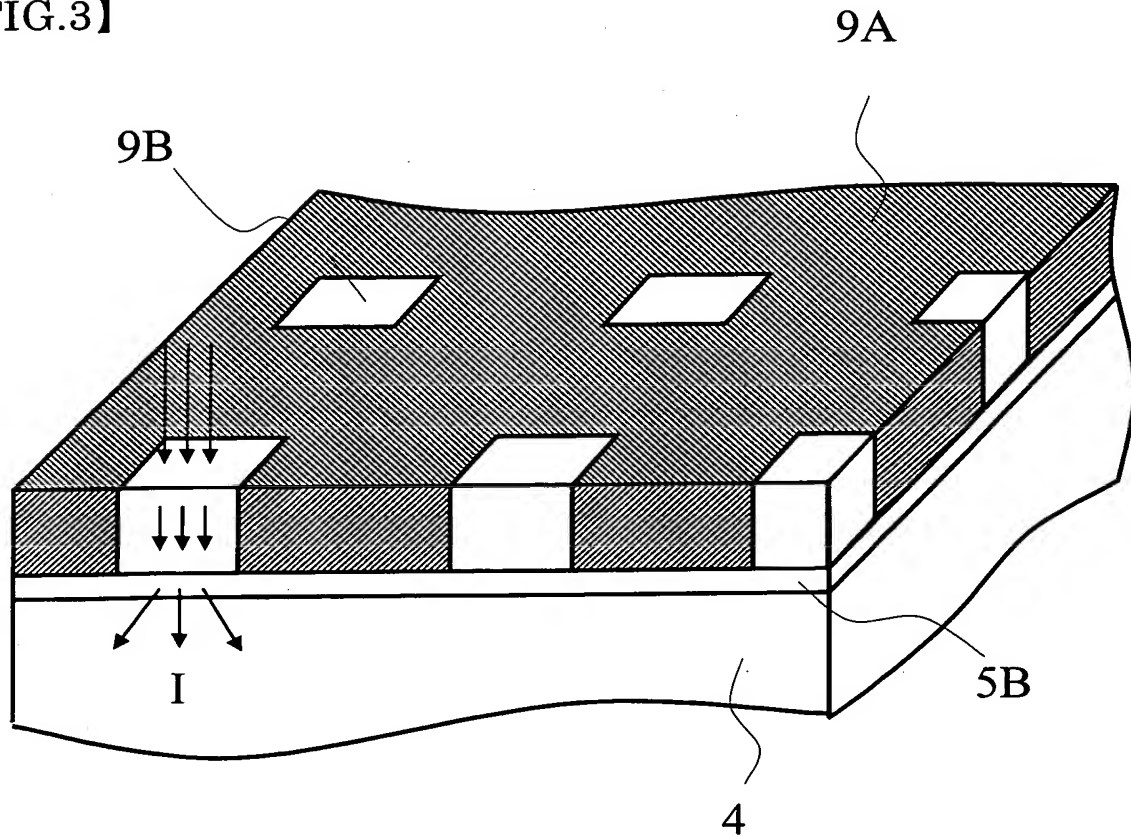
【FIG.1】



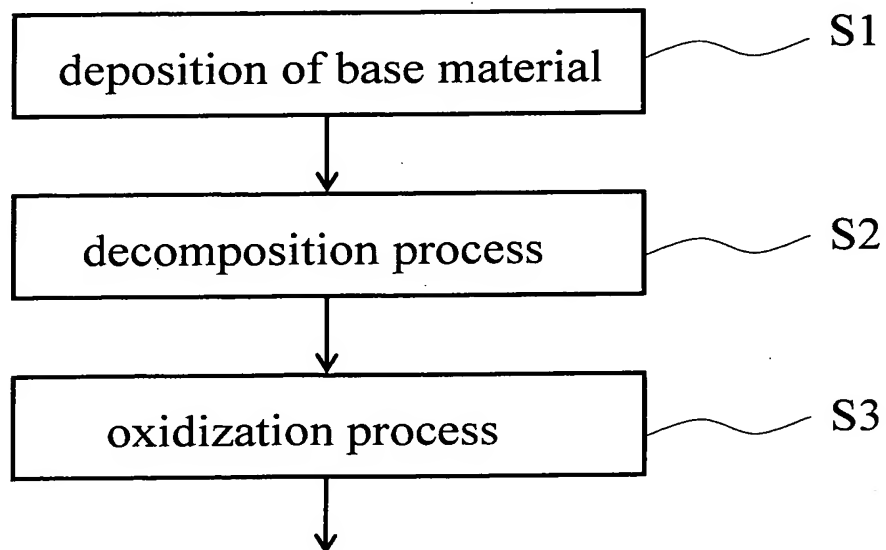
【FIG.2】



【FIG.3】

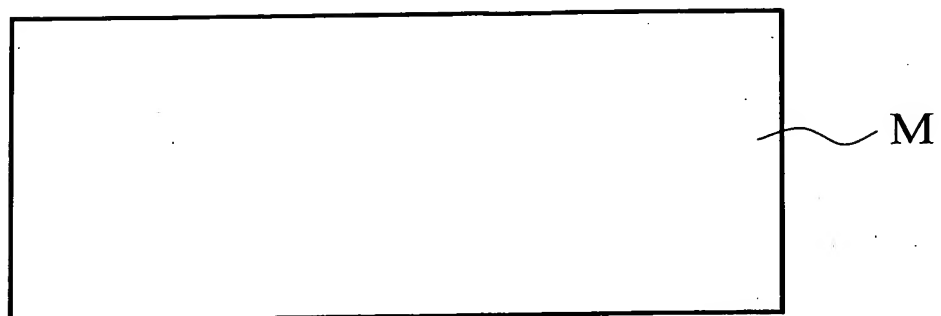


【FIG.4】

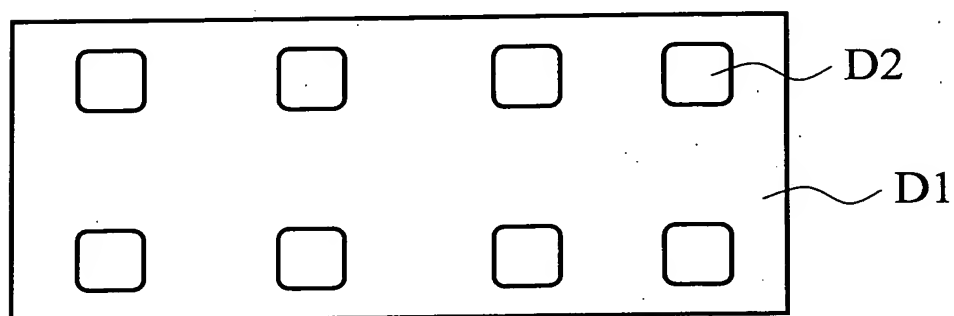


【FIG.5】

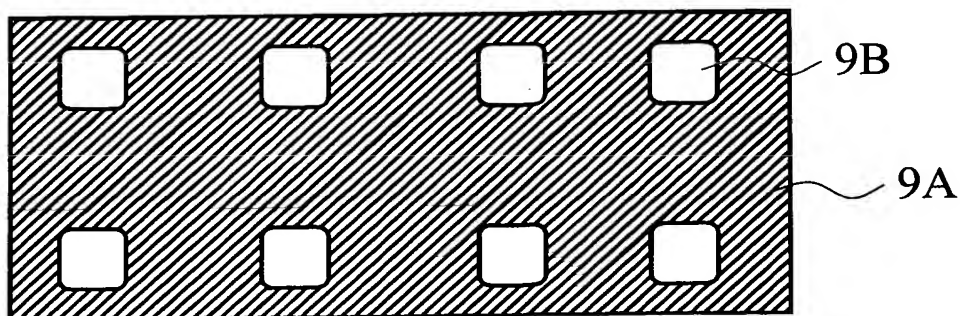
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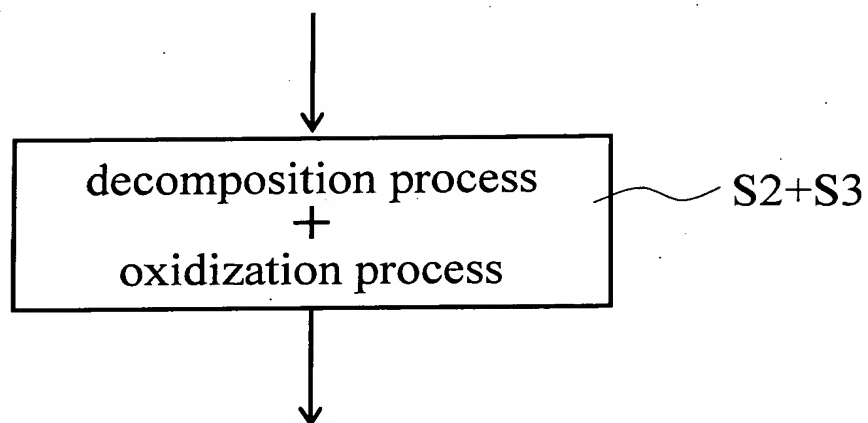
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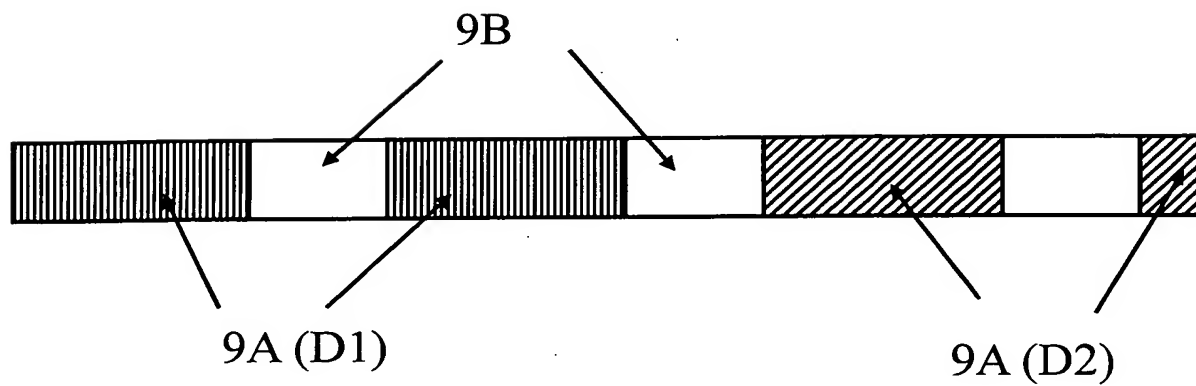
(c)



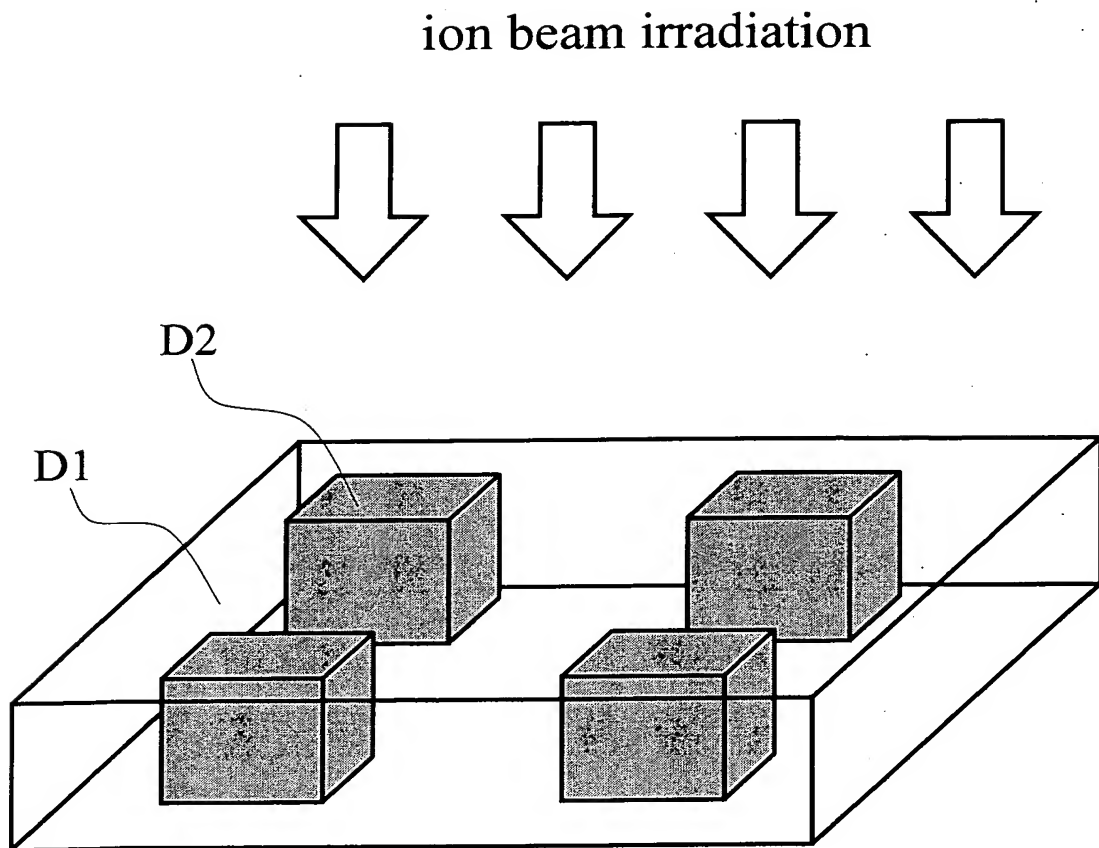
【FIG.6】



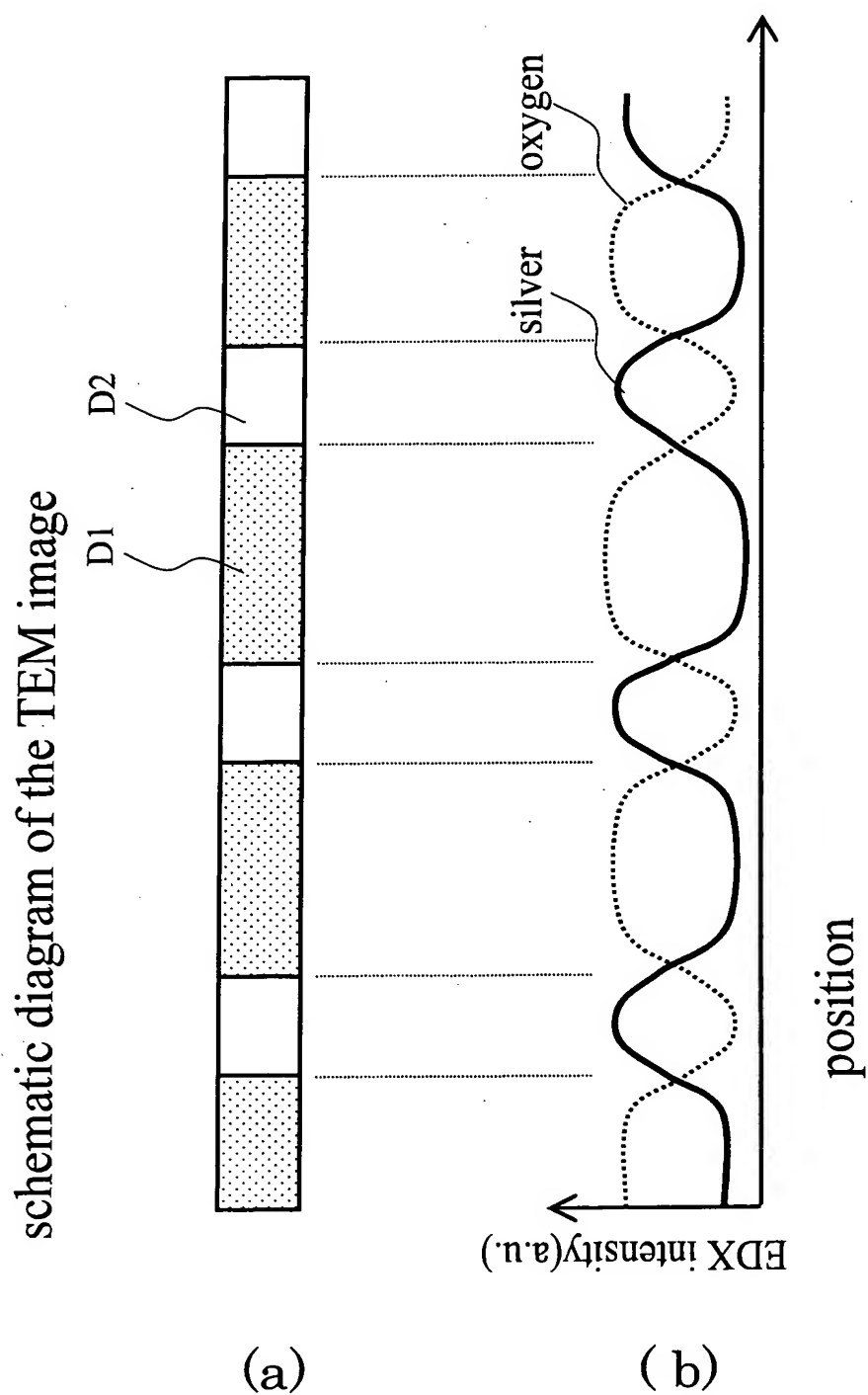
【FIG.7】



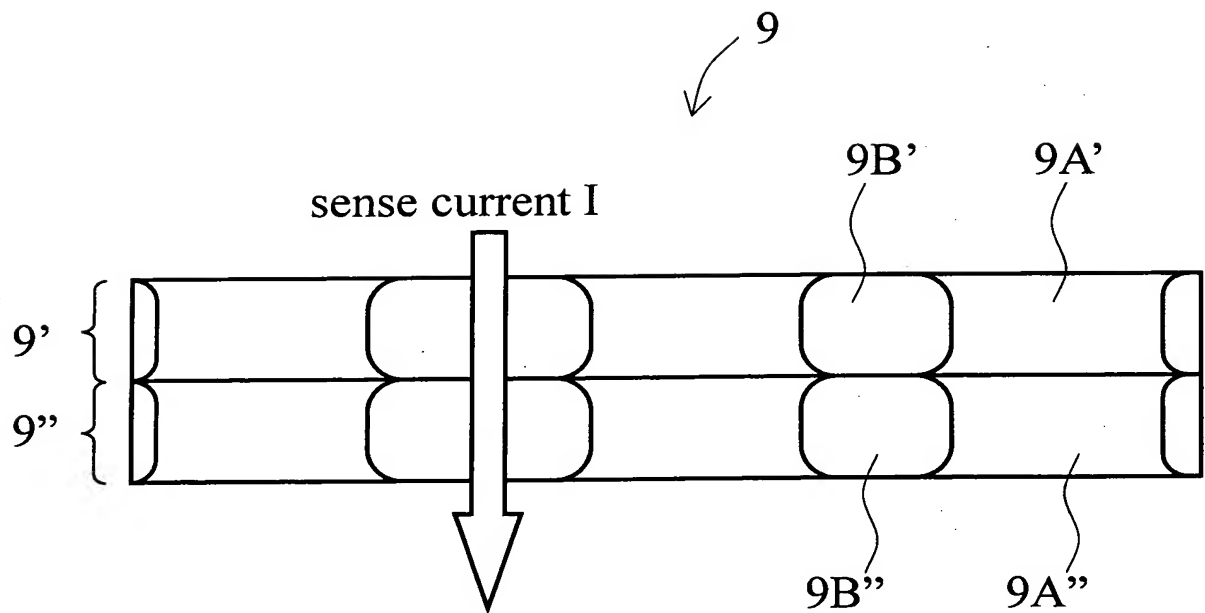
【FIG.8】



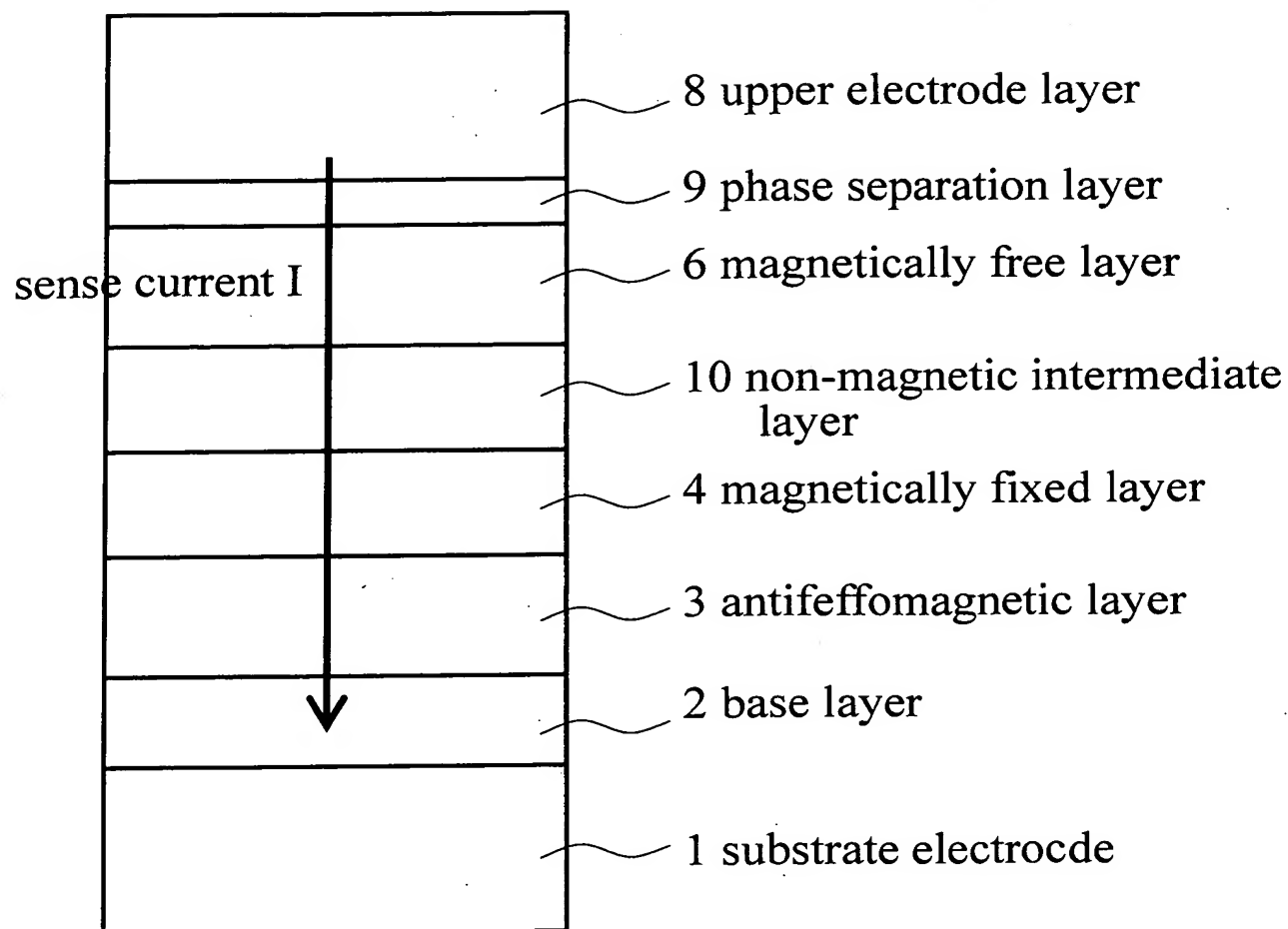
【FIG.9】



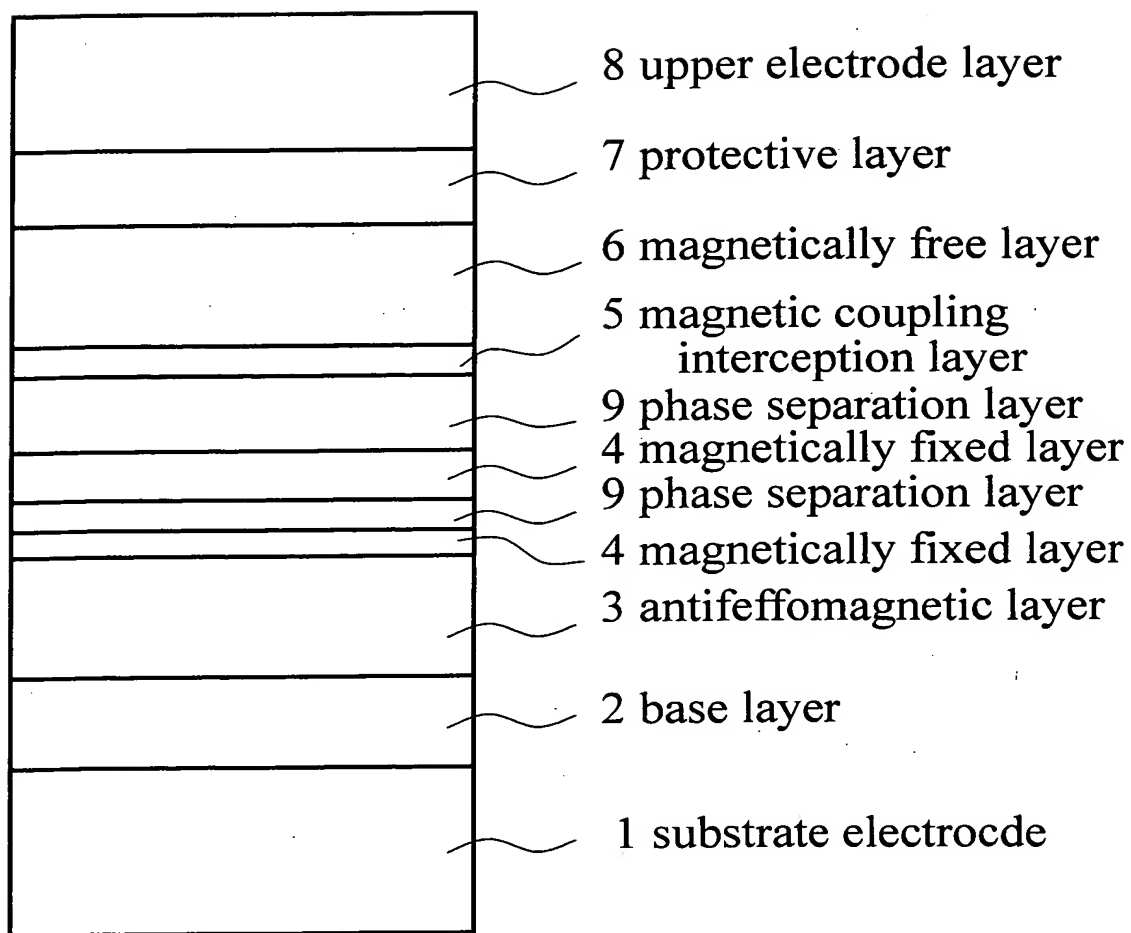
【FIG.10】



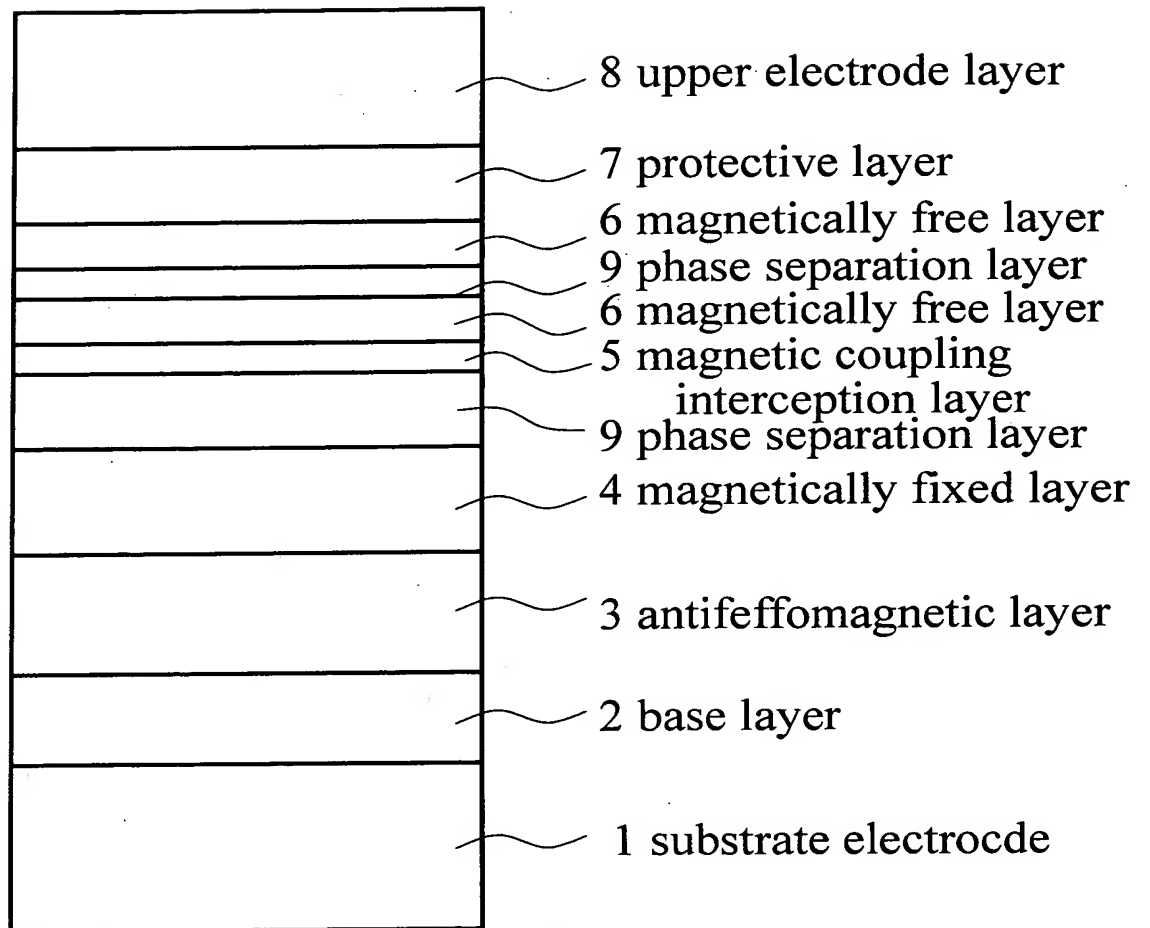
【FIG.11】



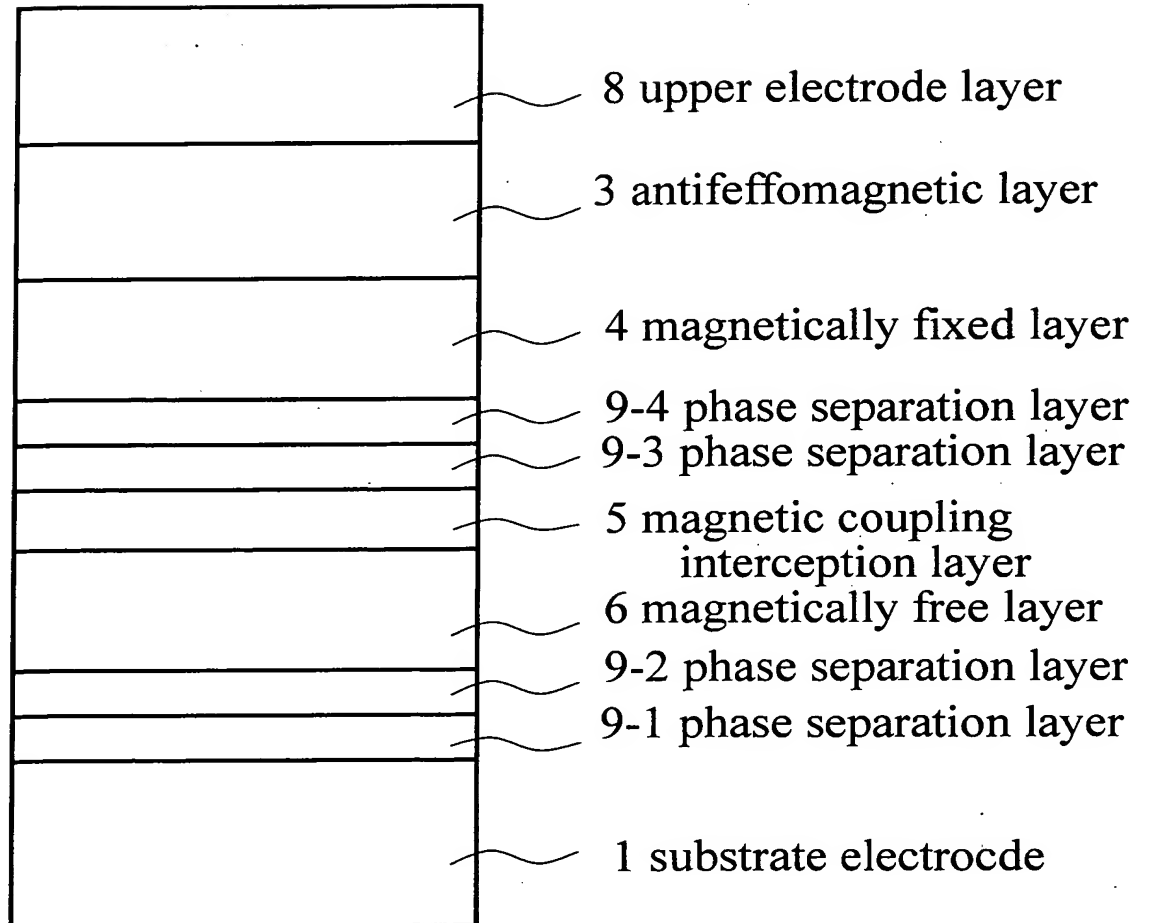
【FIG.12】



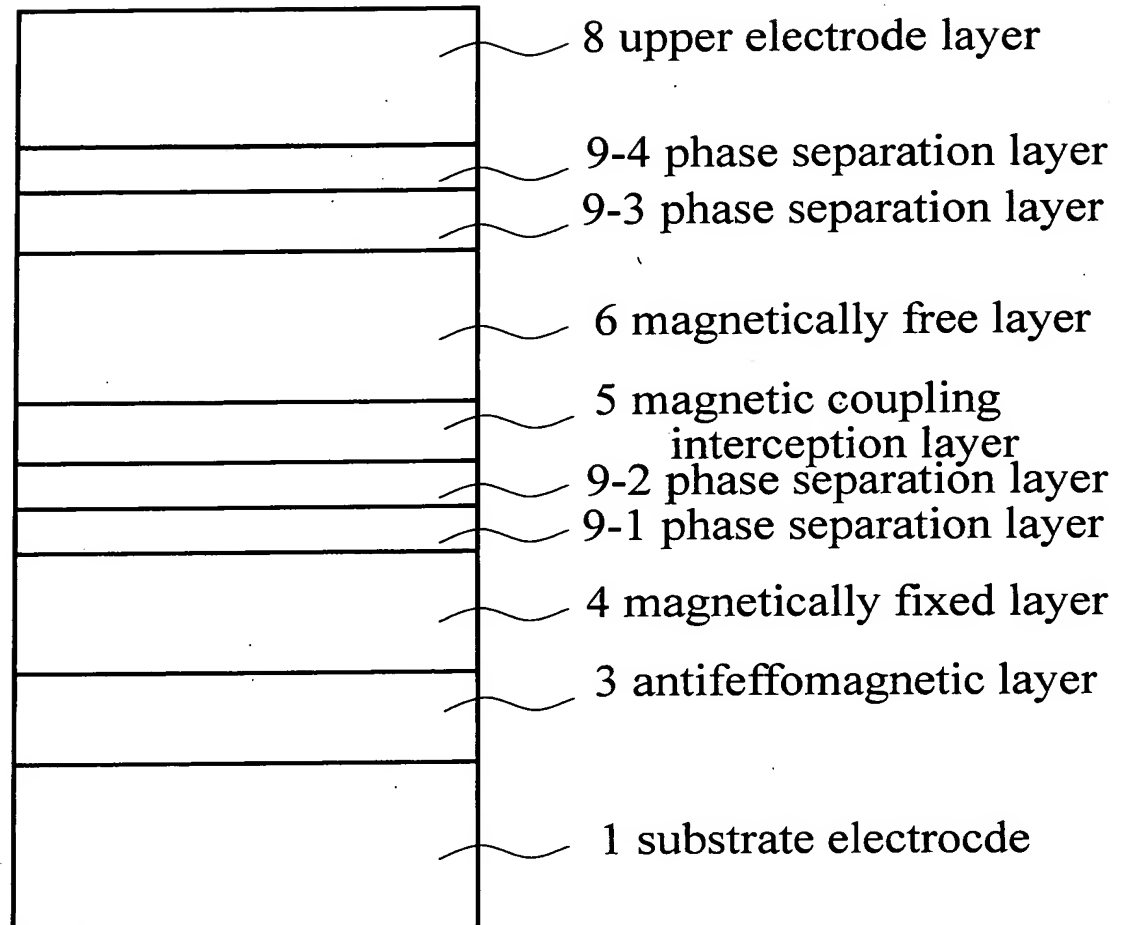
【FIG.13】



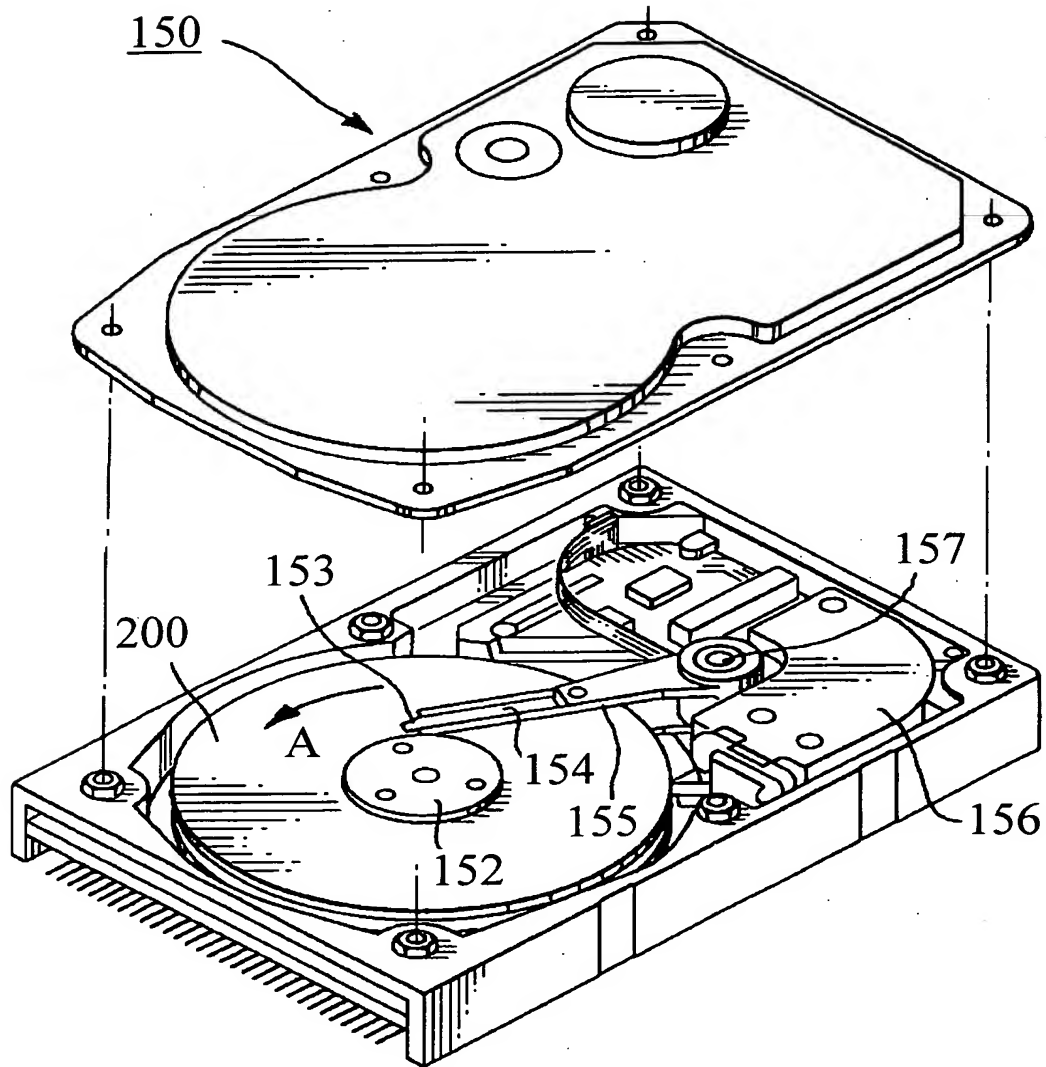
【FIG.14】



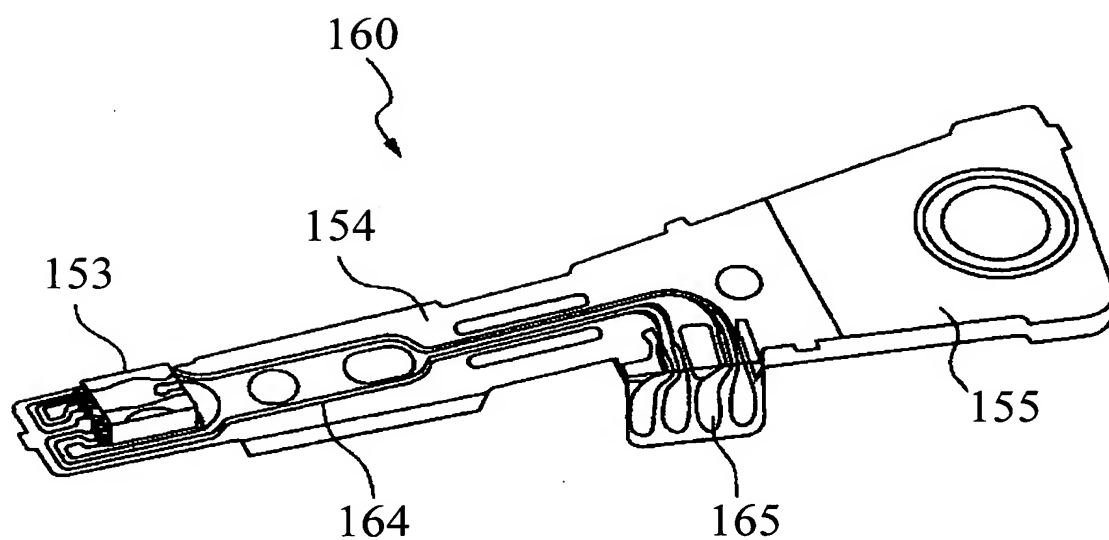
【FIG.15】



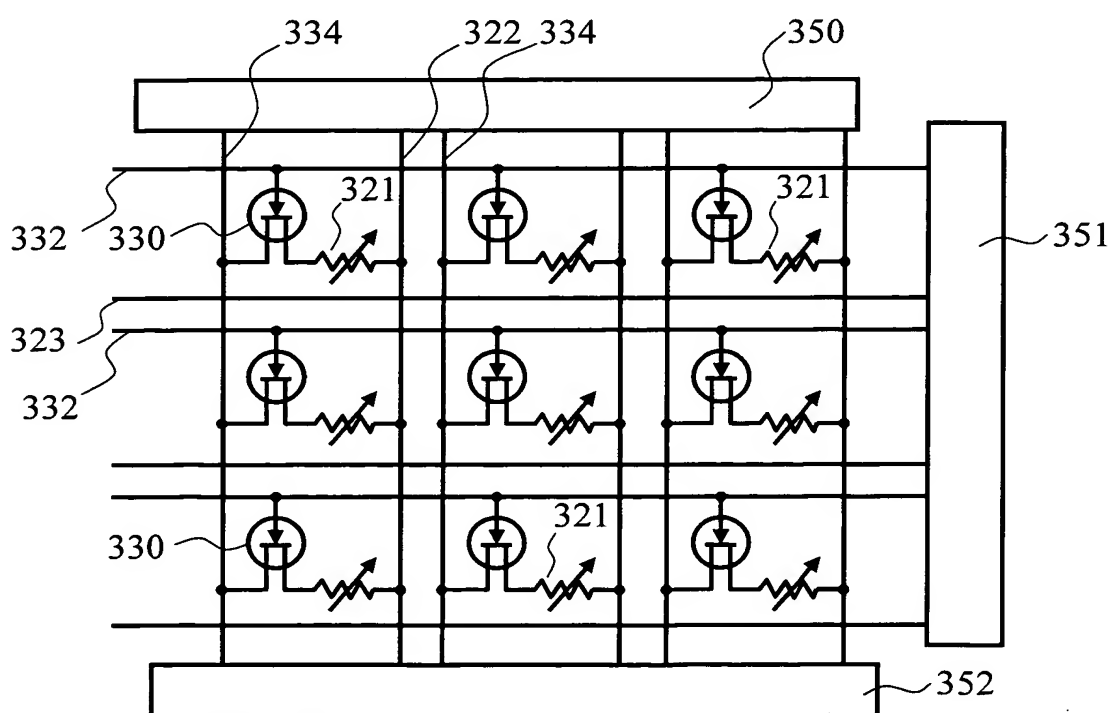
【FIG.16】



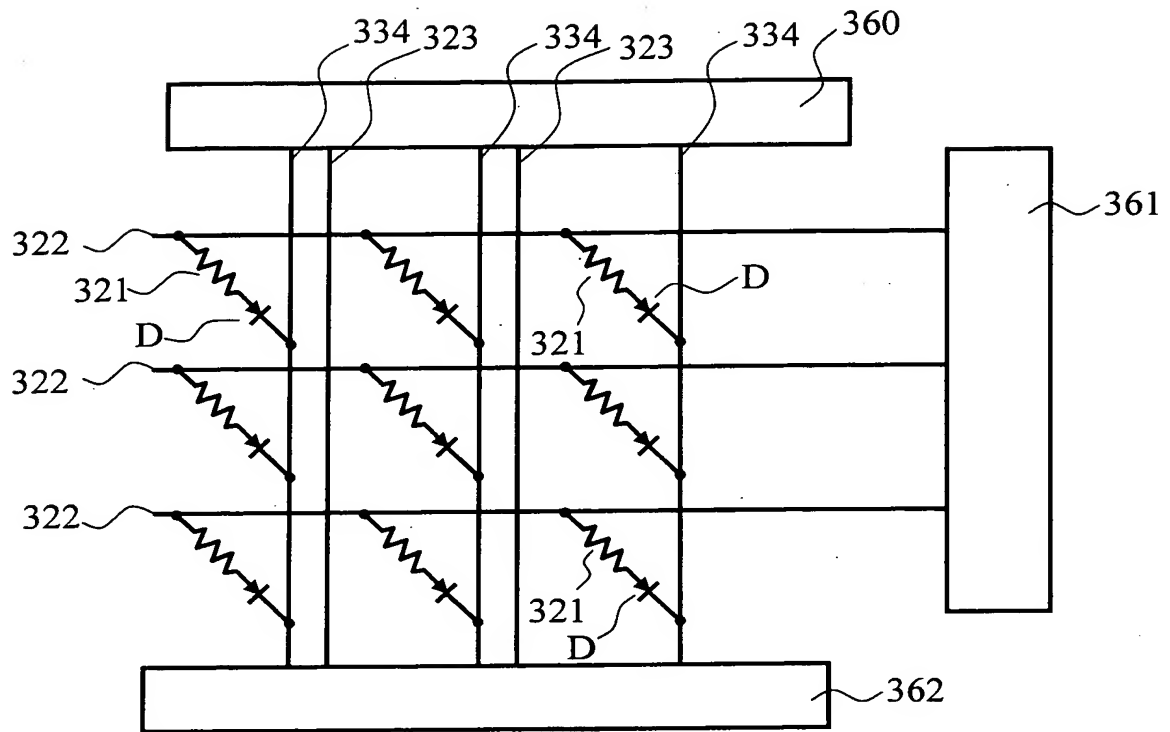
【FIG.17】



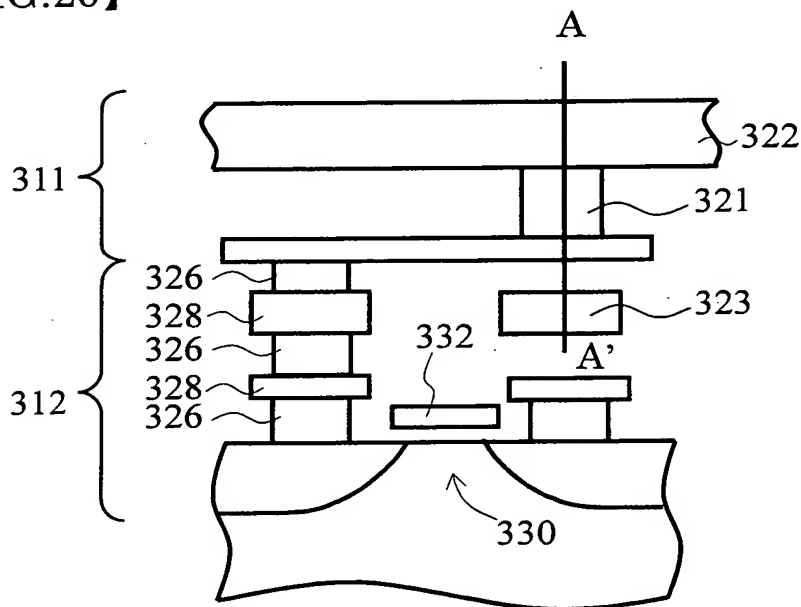
【FIG.18】



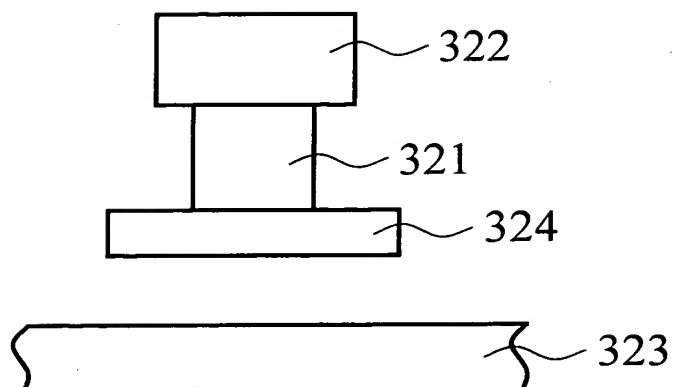
【FIG.19】



【FIG.20】



【FIG.21】



【FIG.22】

